Lightning NO Production in the GMI Model

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Outline

- Current procedure in GMI model
- Necessity of co-locating lightning NO with convective transport
- Parameterization development for GMI
- Implementation and Results

Current Procedure

- Climatological monthly spatial distributions of total (CG+IC) lightning flashes (Price et al., 1997) based on ISCCP deep convective cloud top heights (Price and Rind, 1992).
- CG fraction based on cold cloud depth (Price and Rind, 1993)
- $P_{CG} = 10\ P_{IC}$; $P_{CG} = 6.7 \times 10^{26}$ molec/flash or ~1100 moles/flash (Price et al., 1997)
- Grid cell NO production values scaled such that global production equals a specified value (e.g., 5 TgN/yr)
- Vertically distributed according to C-shape profiles derived from cloud-resolving model simulations of Pickering et al. (1998)

Lightning NO and Convective Transport

- Use of climatological lightning NO production results in lightning NO not being injected into the model at same times and locations as at which the model convective transport occurs
- Therefore, lightning NO and convectively-transported species (HO_x precursors, NO_x, CO, NMHC) are introduced to the upper troposphere in different locations
- Results in "fuzzy" middle and upper tropospheric chemistry
- Lightning and convection need to be co-located!

Available Parameterizations

LIGHTNING FLASH RATES MUST BE PARAMETERIZED IN TERMS OF VARIABLES FROM THE MODEL CONVECTIVE SCHEME

- Cloud-height-based approach

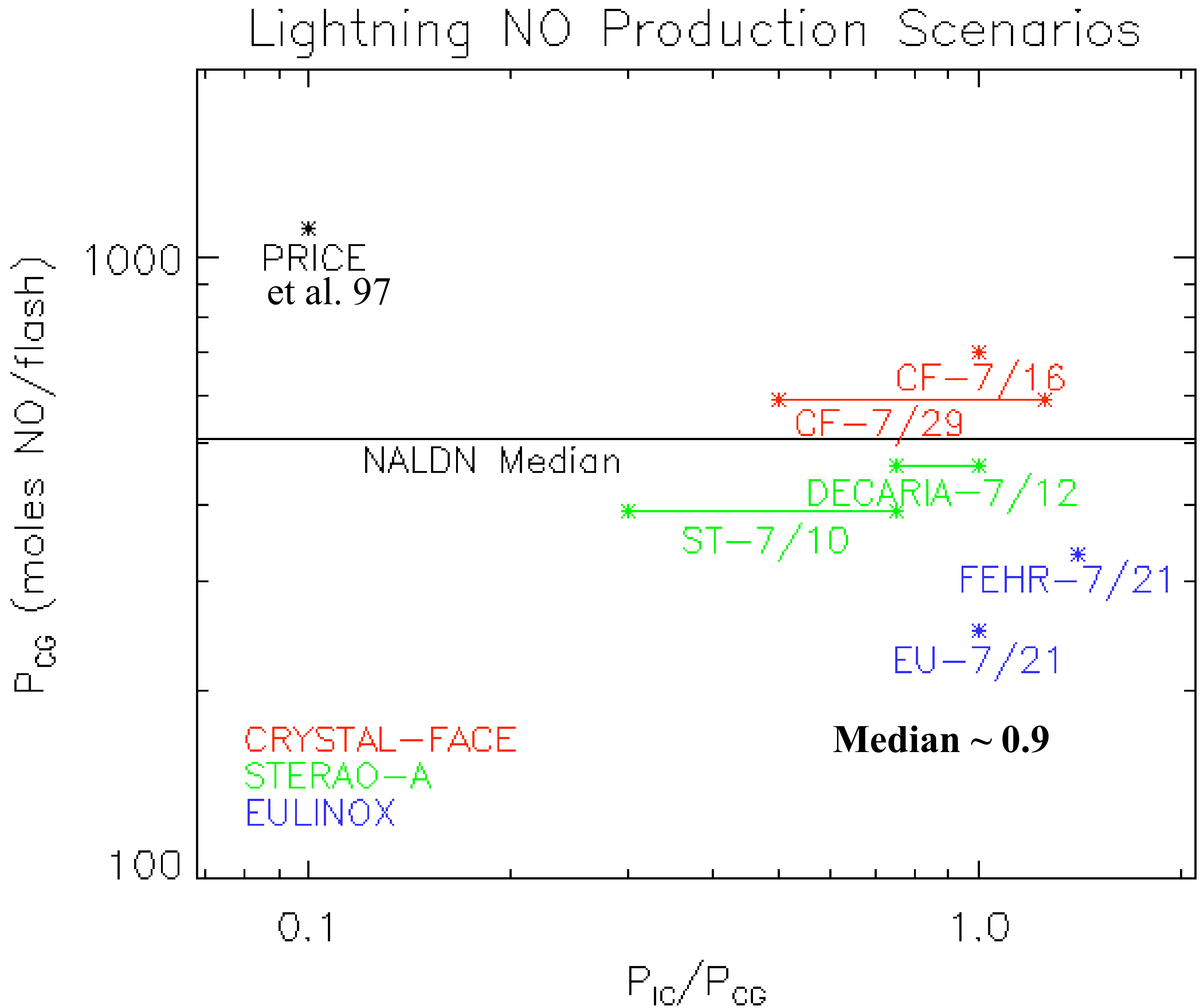
  Price and Rind (1992)
- Cloud-mass flux based approach ← **BEST**

  Allen and Pickering (2002)
- Convective precipitation based approach

  Allen and Pickering (2002)

Other Changes

Evidence is mounting that refutes the assumption that $P_{CG} = 10\ P_{IC}$. We are now assuming $P_{CG} \sim P_{IC}$.



Lightning NO Production Scenarios
PRICE
et al. 97
CF−7/16
CF−7/29
NALDN Median
DECARIA−7/12
ST−7/10
FEHR−7/21
EU−7/21
CRYSTAL−FACE
STERAO−A
EULINOX
Median ~ 0.9
1000
100
0.1
1.0
P_CG (moles NO/flash)
P_IC/P_CG

Other Changes

Estimates of IC/CG flash ratio not necessary.

Boccippio et al. (2002) analysis of IC/CG ratio over U.S. based on OTD and NLDN indicates that storm intensity, morphology, and level of organization have much more impact on IC/CG ratios than environmental variables that can be extracted from GCM output.

CG flashes estimated from cloud mass fluxes will be scaled up to total flashes based on OTD/LIS climatology.

Step 1: Polynomial construction

- **Data**: NLDN/LRF 6-hr avg 4º x 5º CG flash rates for 1997
- **Model output**: Convective mass flux (CLDMAS) at 0, 6, 12, 18 UT
- i=1: GMAO analyzed fields at ~353 hPa for Mar-Dec ‘97, Jan-Feb ‘98
- i=2: FVGCM-fields at ~434 hPa for model year
- i=3: GISS GCM-fields at ~374 hPa for model year
- **Geographic Region**: 10º-60ºN; 120º-60ºW

Polynomial fit to normalized CLDMAS

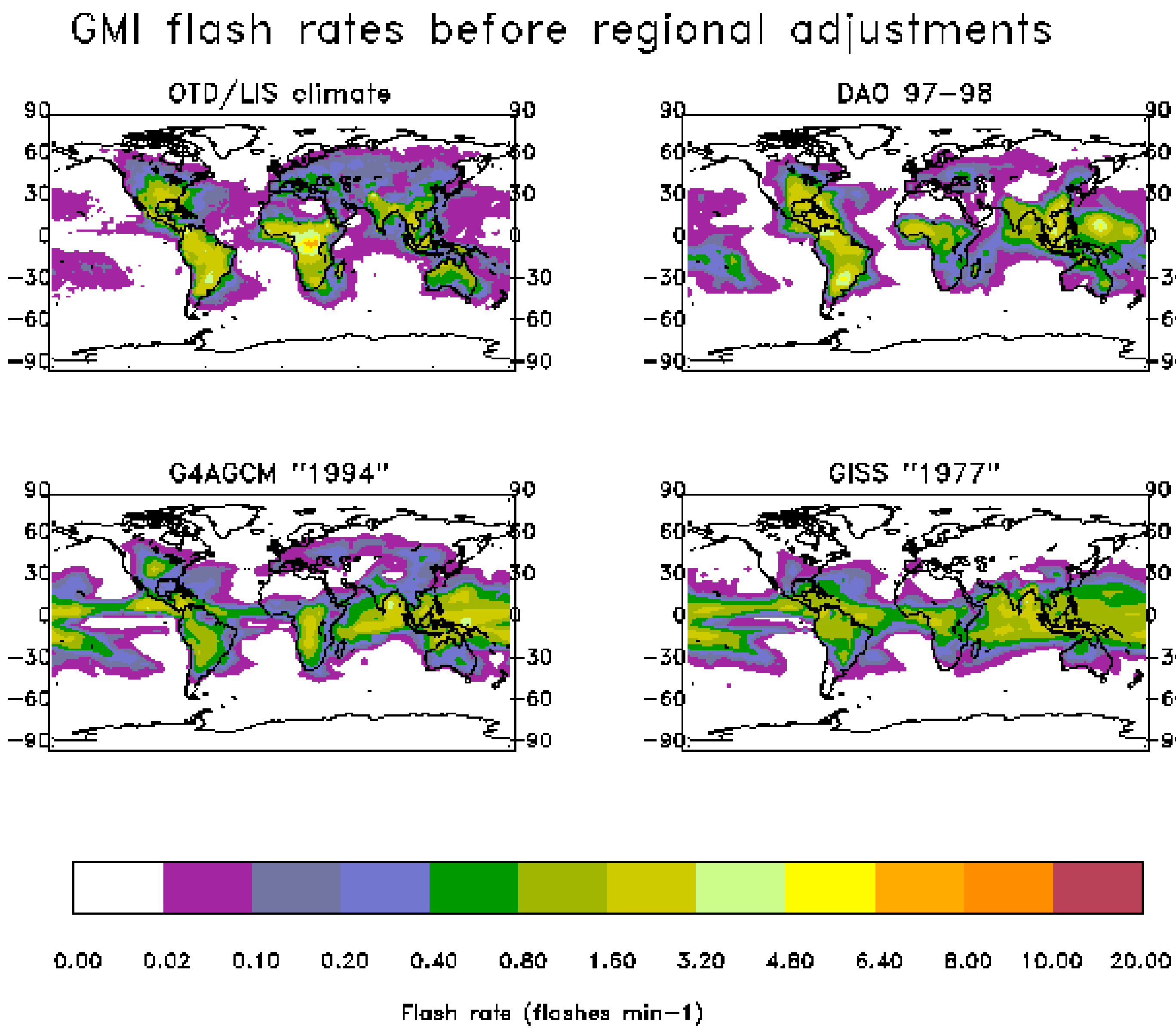
- 1. For 10º-60ºN, 120º-60ºW, extract 00, 06, 12, and 18 UT time-averaged CLDMAS at model-specific pressure levels

- 2. Normalize CLDMAS by dividing by model-dependent mean(CLDMAS)+2*sigma(CLDMAS)
- x_i = $CLDMAS_i$ / [mean($CLDMAS_i$)+2*sigma($CLDMAS_i$)]
- y = NLDN/LRF CG flash rates

- 3. For i=1,3 do sort x_i and y independently by magnitude

- 4. For i=1,3 do fit polynomial ($y_{fit} = ax_i + b[x_i]^2+c[x_i]^3$)

- 5. Adjust y_{fit} for area of grid box; Constrain to be ≥ 0



GMI flash rates before regional adjustments
OTD/LIS climate
DAO 97-98
G4AGCM "1994"
GISS "1977"
90
60
30
0
-30
-60
-90
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min-1)

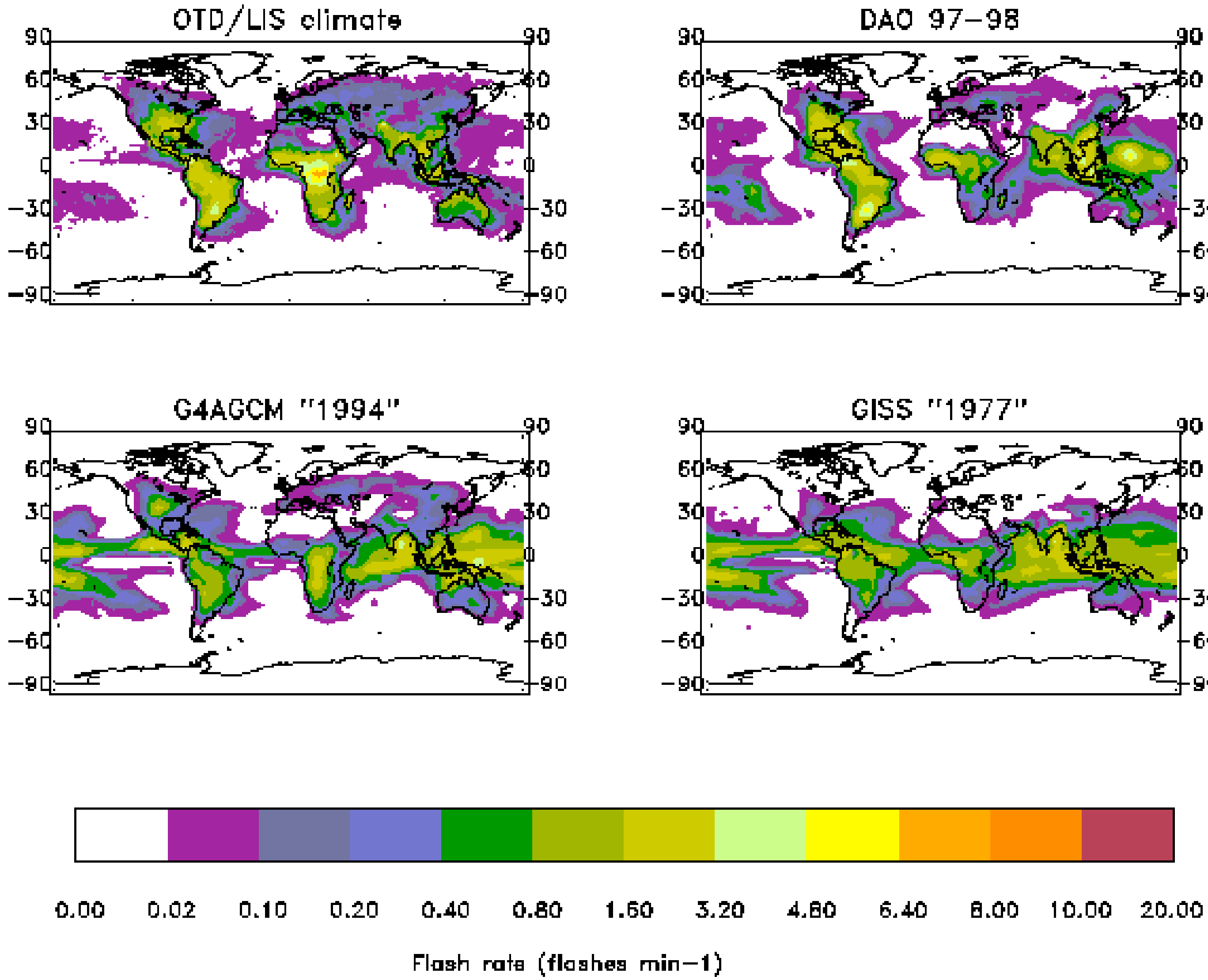
Step 2: Adjust flash rates to best match OTD/LIS climatology

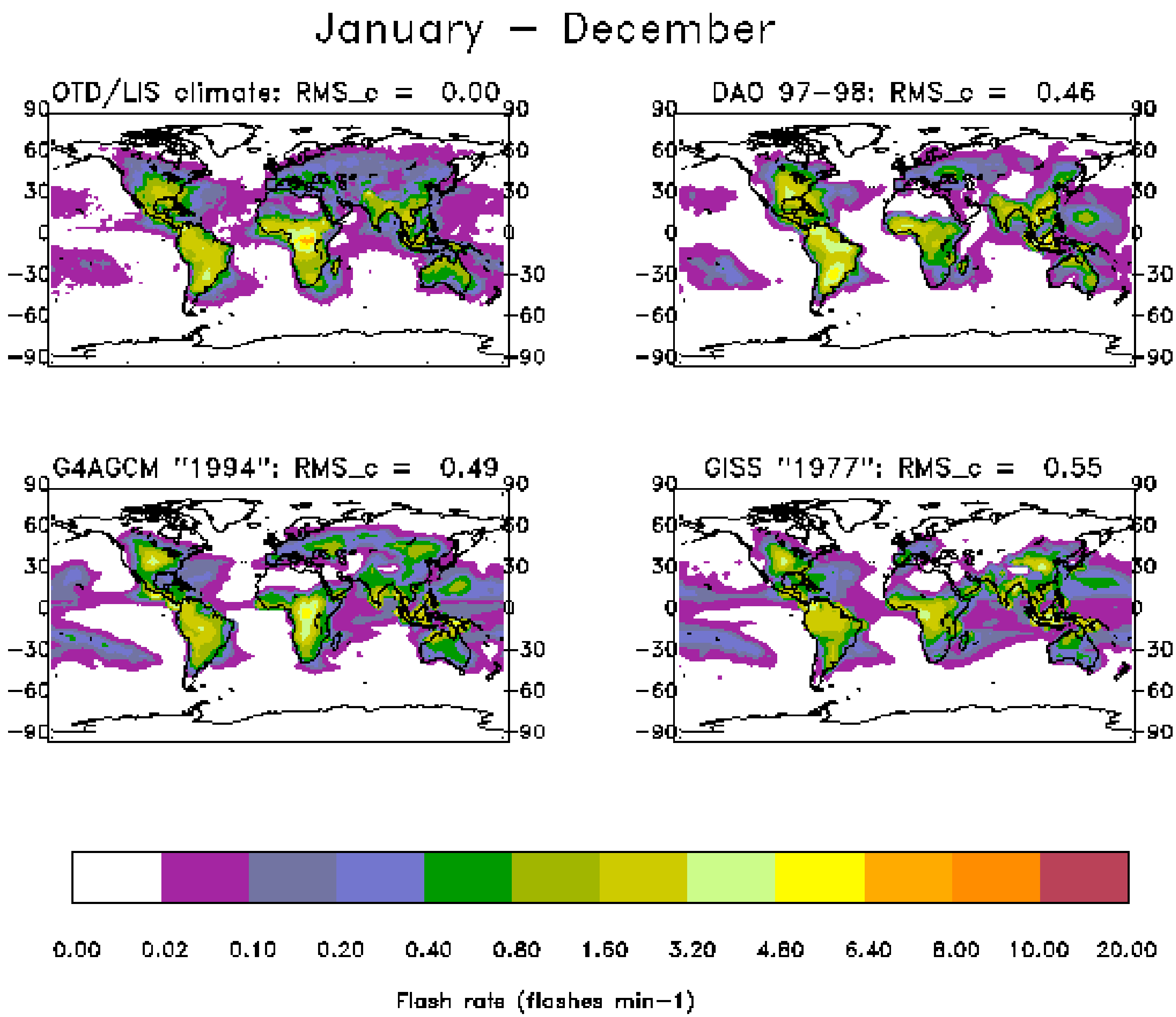
Marine-continental contrast not captured especially in the tropics.

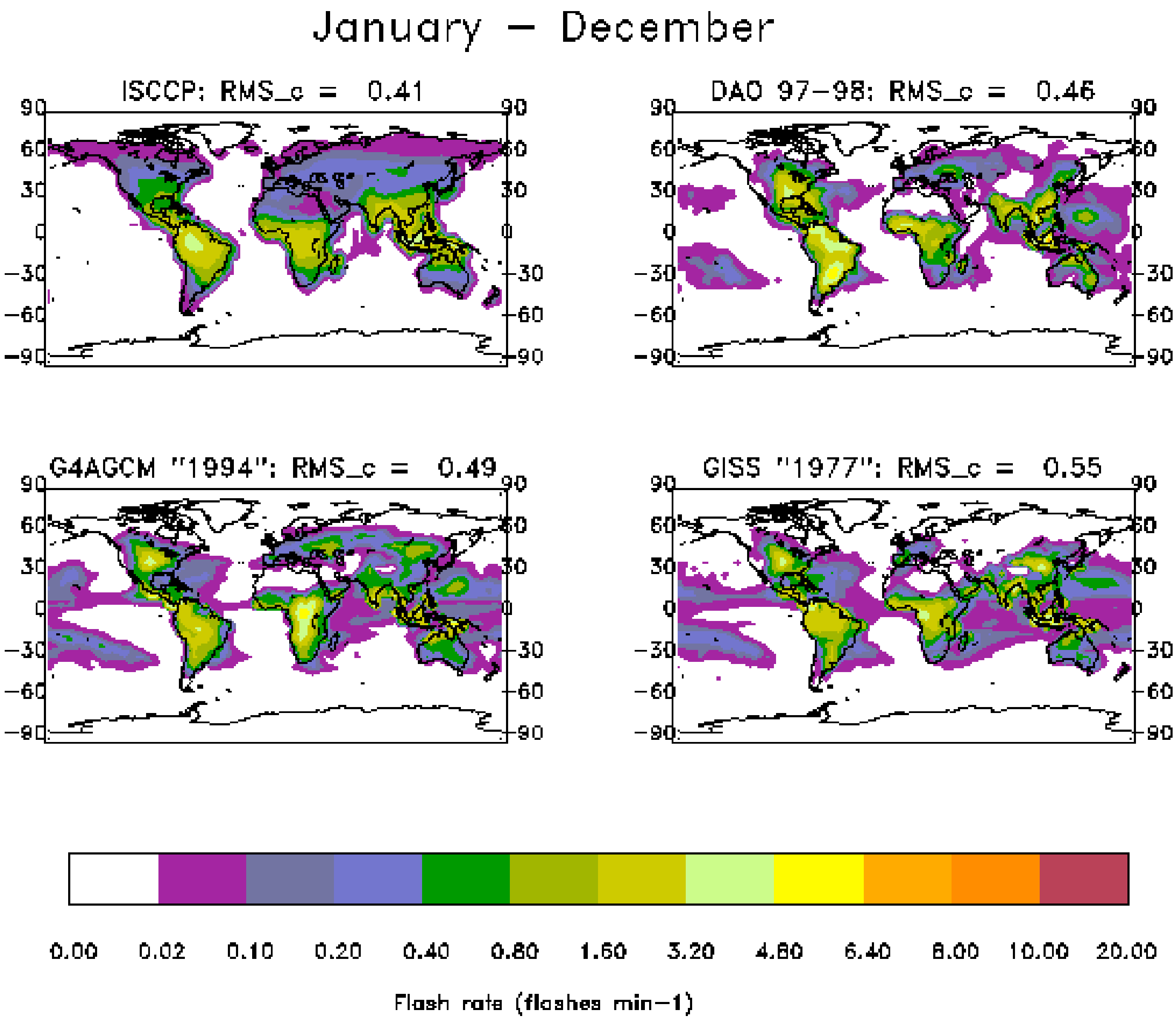
For i=1,3 do

1. Adjust global CG flash rates so that the annual average total global flash rate matches observed total flash rate from v1.0 OTD/LIS climatology (46.6 flashes s^{-1}) [see previous plot]
2. Reduce tropical marine flash rates to best match climatology
3. Increase tropical continental flash rates to best match climatology
4. Adjust midlatitude continental flash rates to best match climatology
5. Constrain flash rates to be < 100 flashes/min based on obs.
6. Adjust global flash rates to match climatology

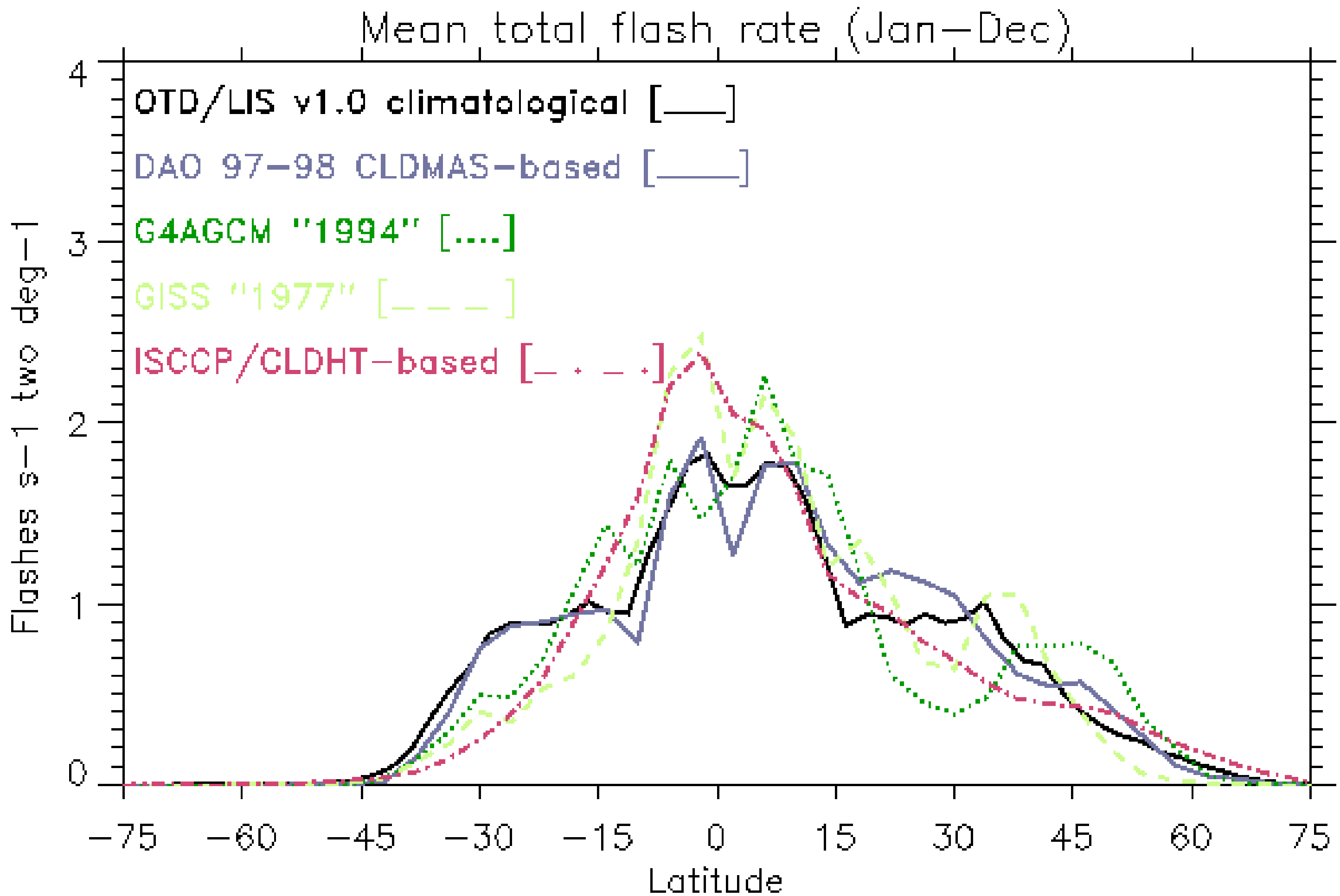
GMI flash rates before regional adjustments




January – December
OTD/LIS climate: RMS_c = 0.00
DAO 97–98: RMS_c = 0.46
G4AGCM "1994": RMS_c = 0.49
GISS "1977": RMS_c = 0.55
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min–1)

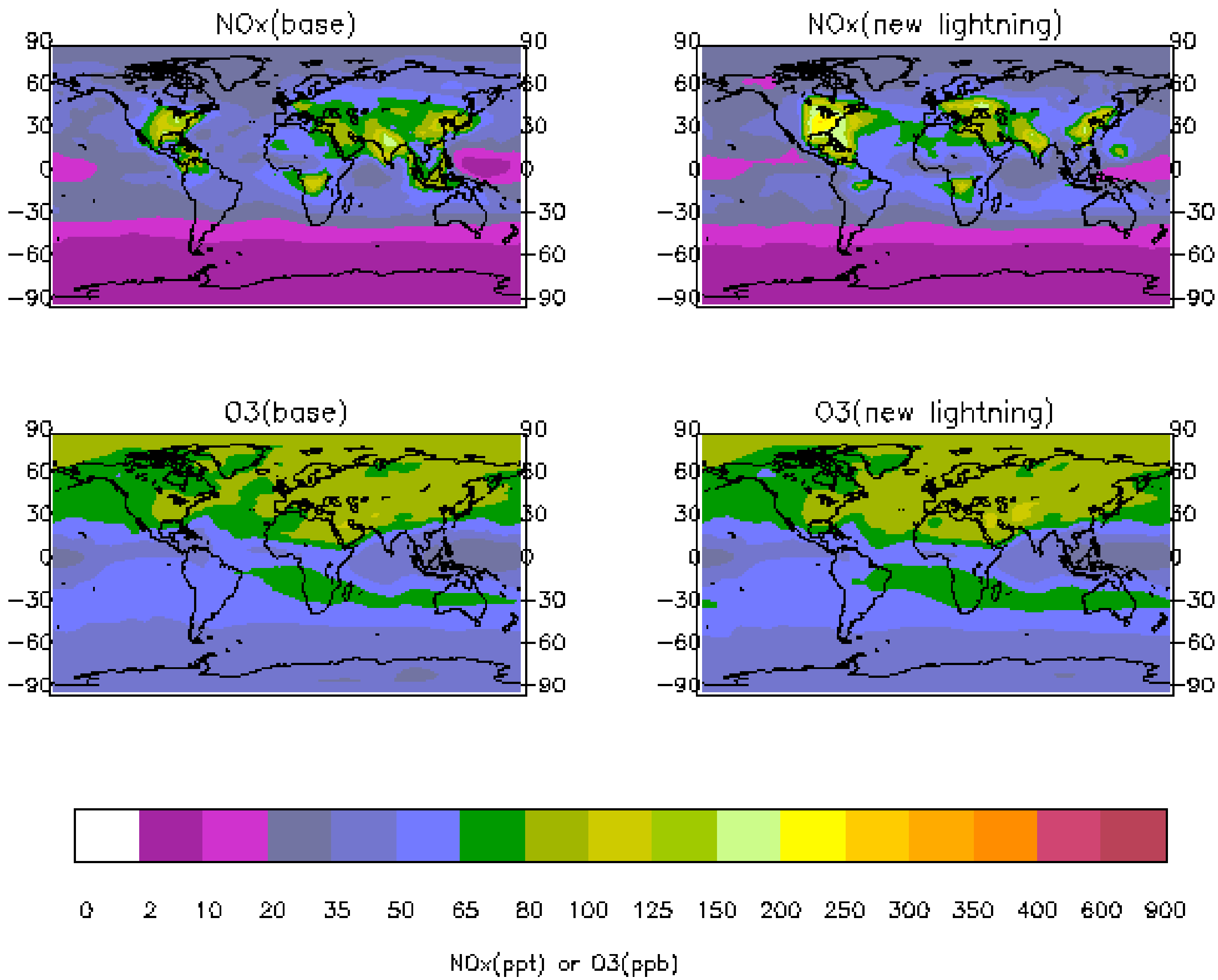


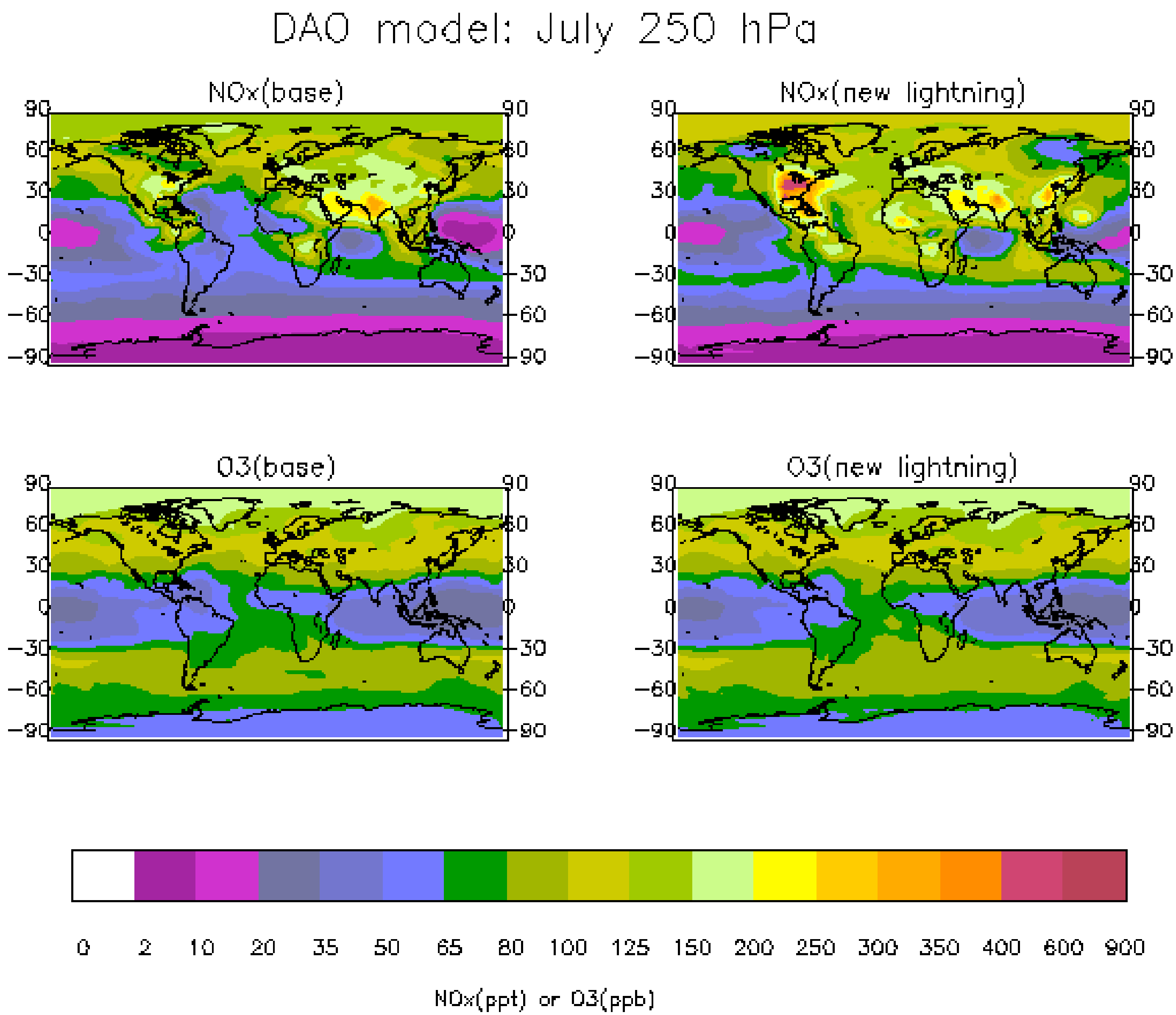
January – December
ISCCP: RMS_c = 0.41
DAO 97–98: RMS_c = 0.46
G4AGCM "1994": RMS_c = 0.49
GISS "1977": RMS_c = 0.55
90
60
30
0
–30
–60
–90
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min–1)



Mean total flash rate (Jan–Dec)
OTD/LIS v1.0 climatological [___]
DAO 97–98 CLDMAS–based [___]
G4AGCM "1994" [....]
GISS "1977" [_ _ _]
ISCCP/CLDHT–based [_ . _ .]
Flashes s–1 two deg–1
Latitude
0
1
2
3
4
–75
–60
–45
–30
–15
0
15
30
45
60
75

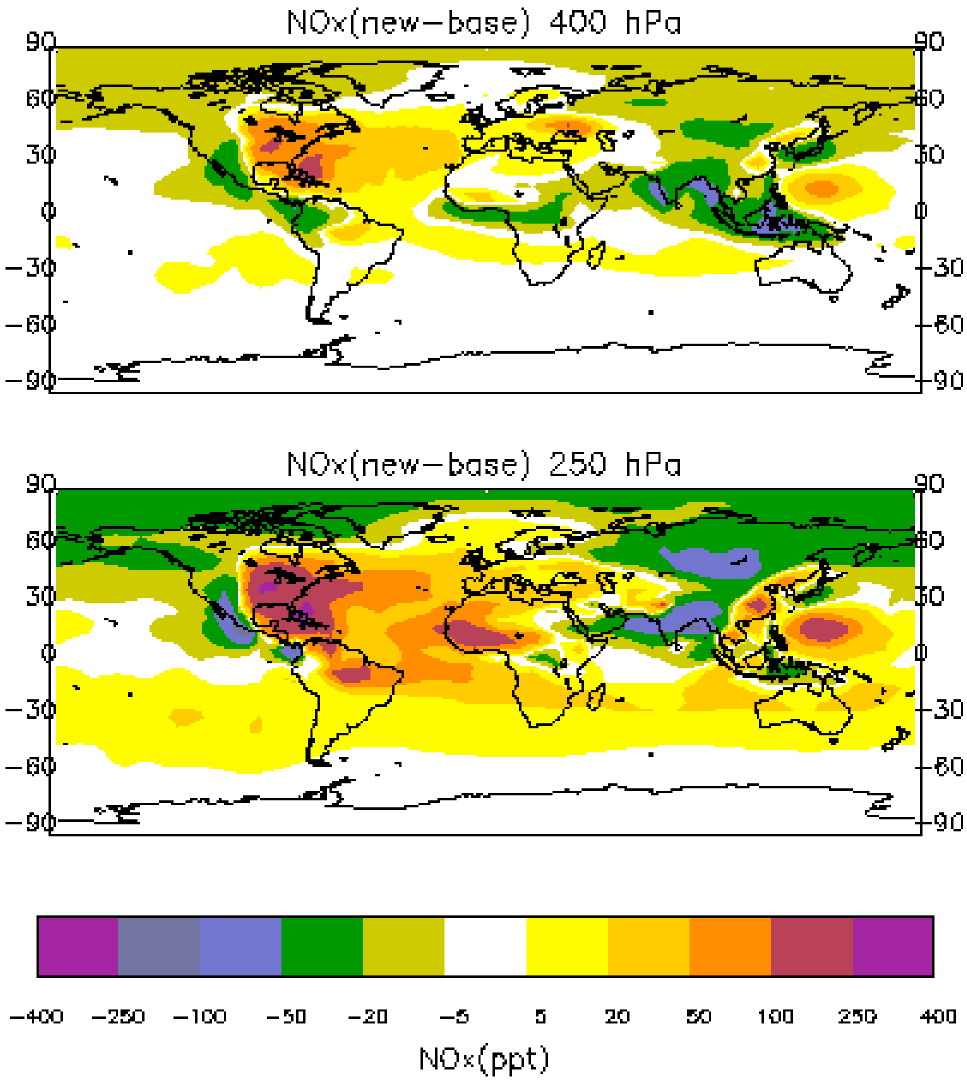
DAO model: July 400 hPa



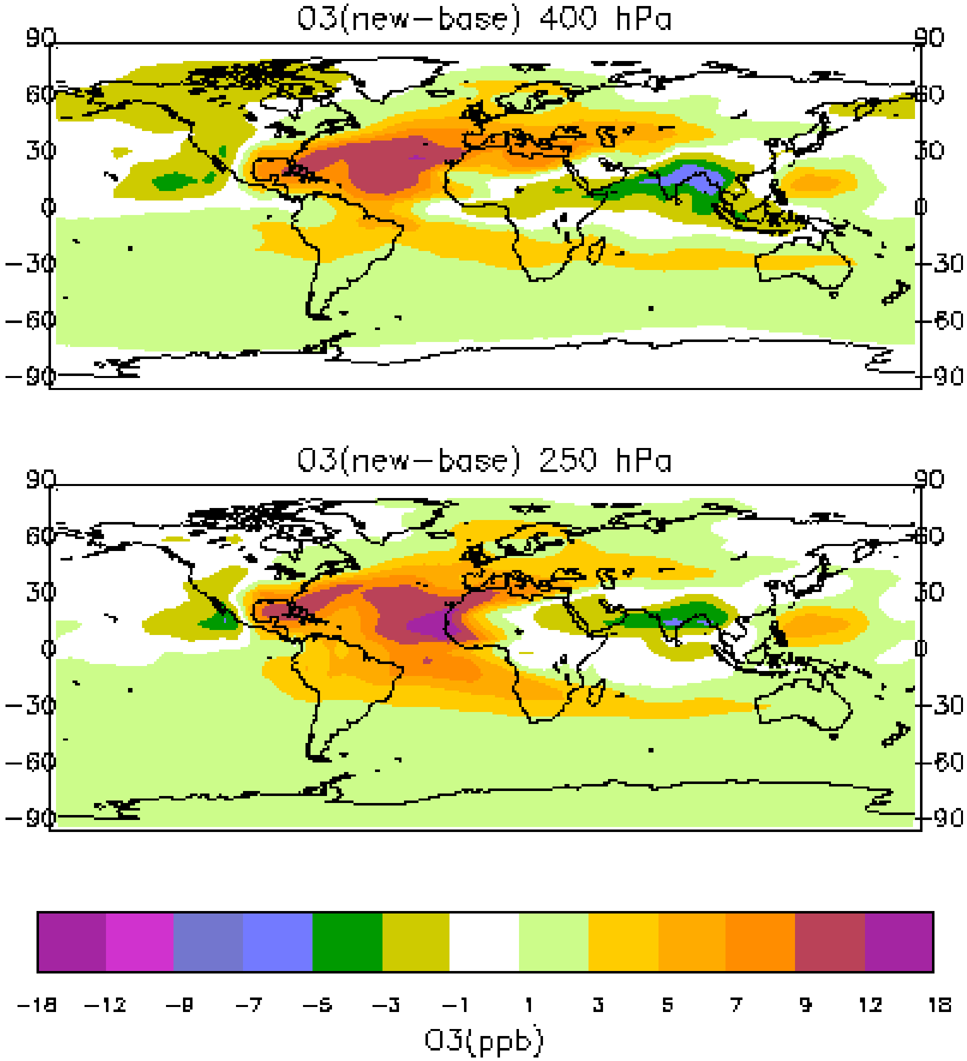


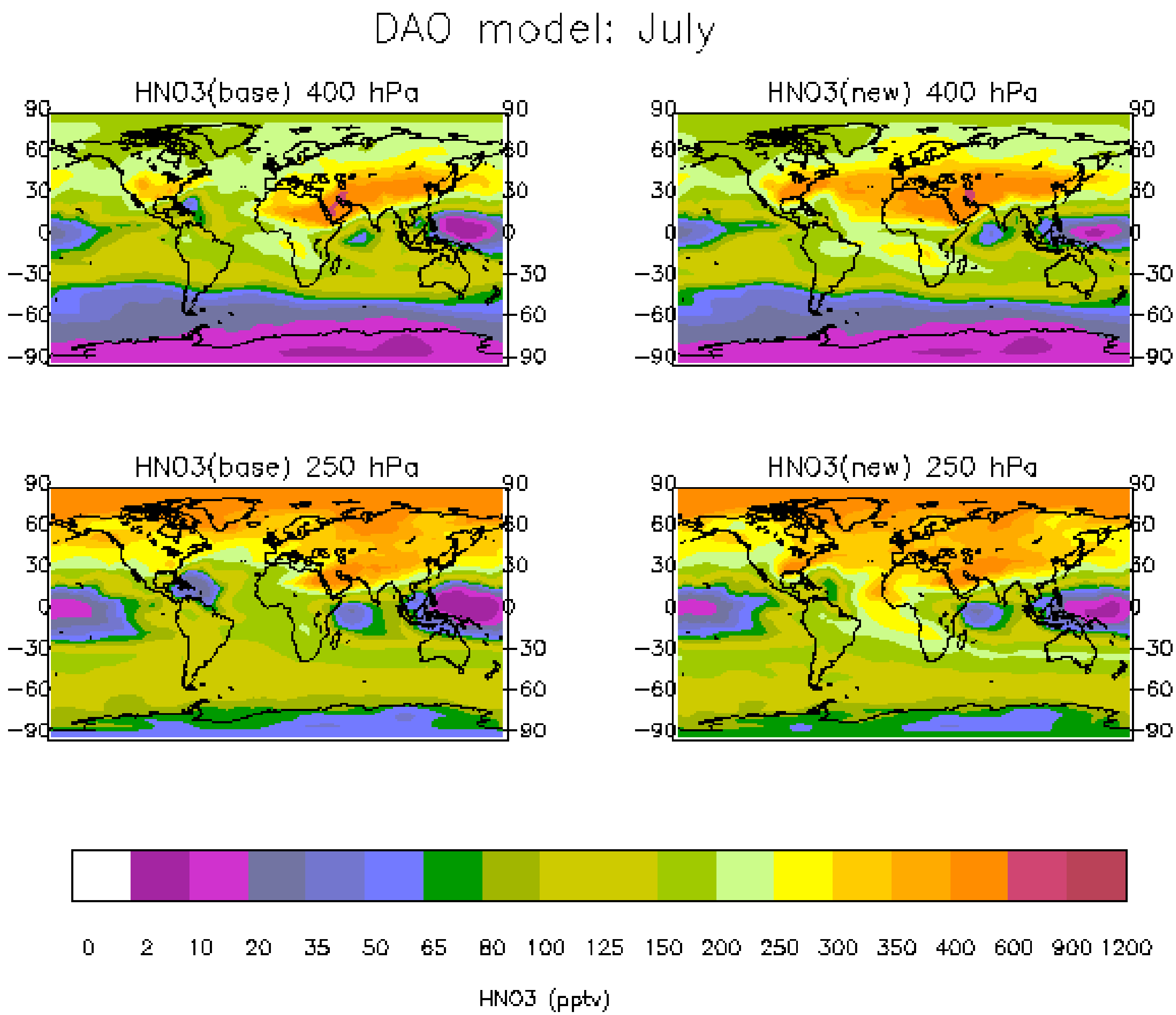
DAO model: July 250 hPa
NOx(base)
NOx(new lightning)
O3(base)
O3(new lightning)
90
60
30
0
−30
−60
−90
0
2
10
20
35
50
65
80
100
125
150
200
250
300
350
400
600
900
NOx(ppt) or O3(ppb)

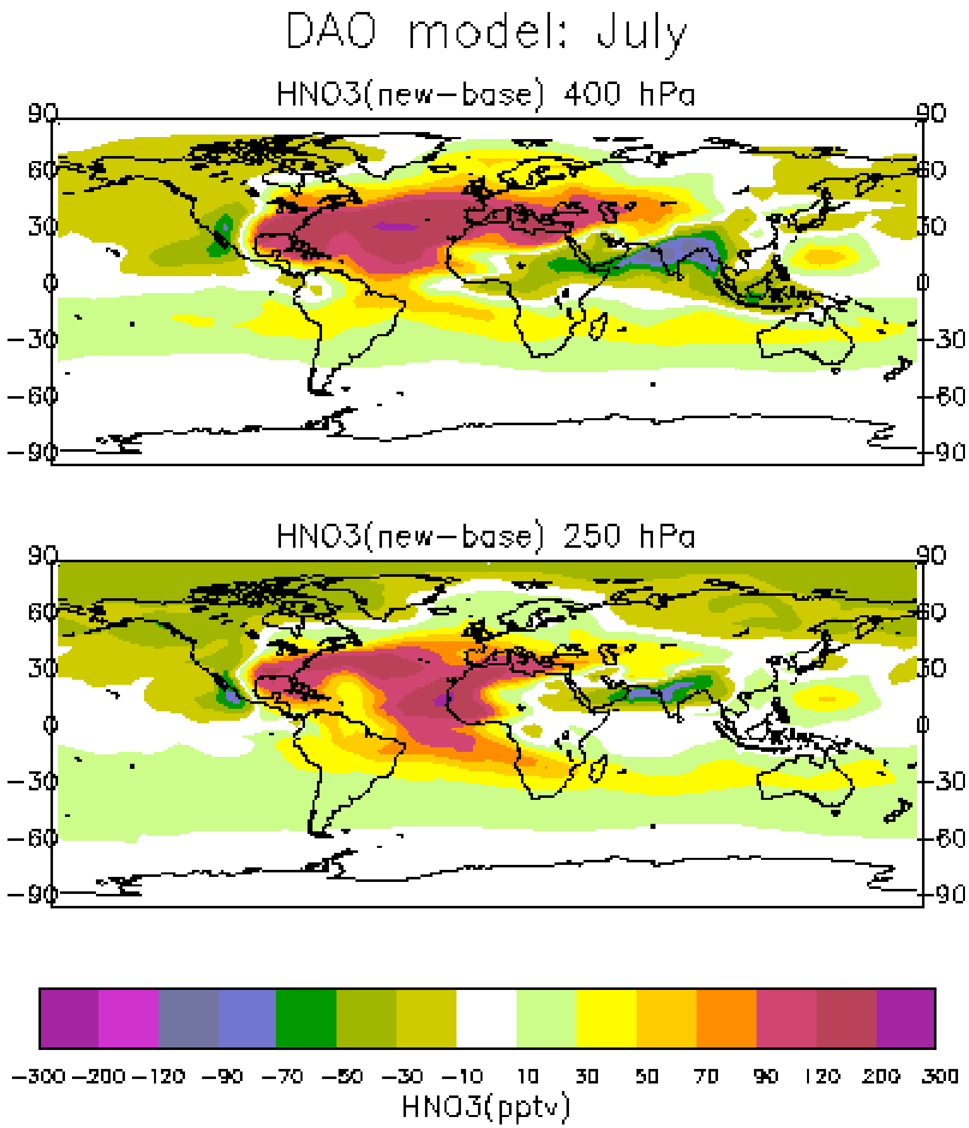
DAO model: July

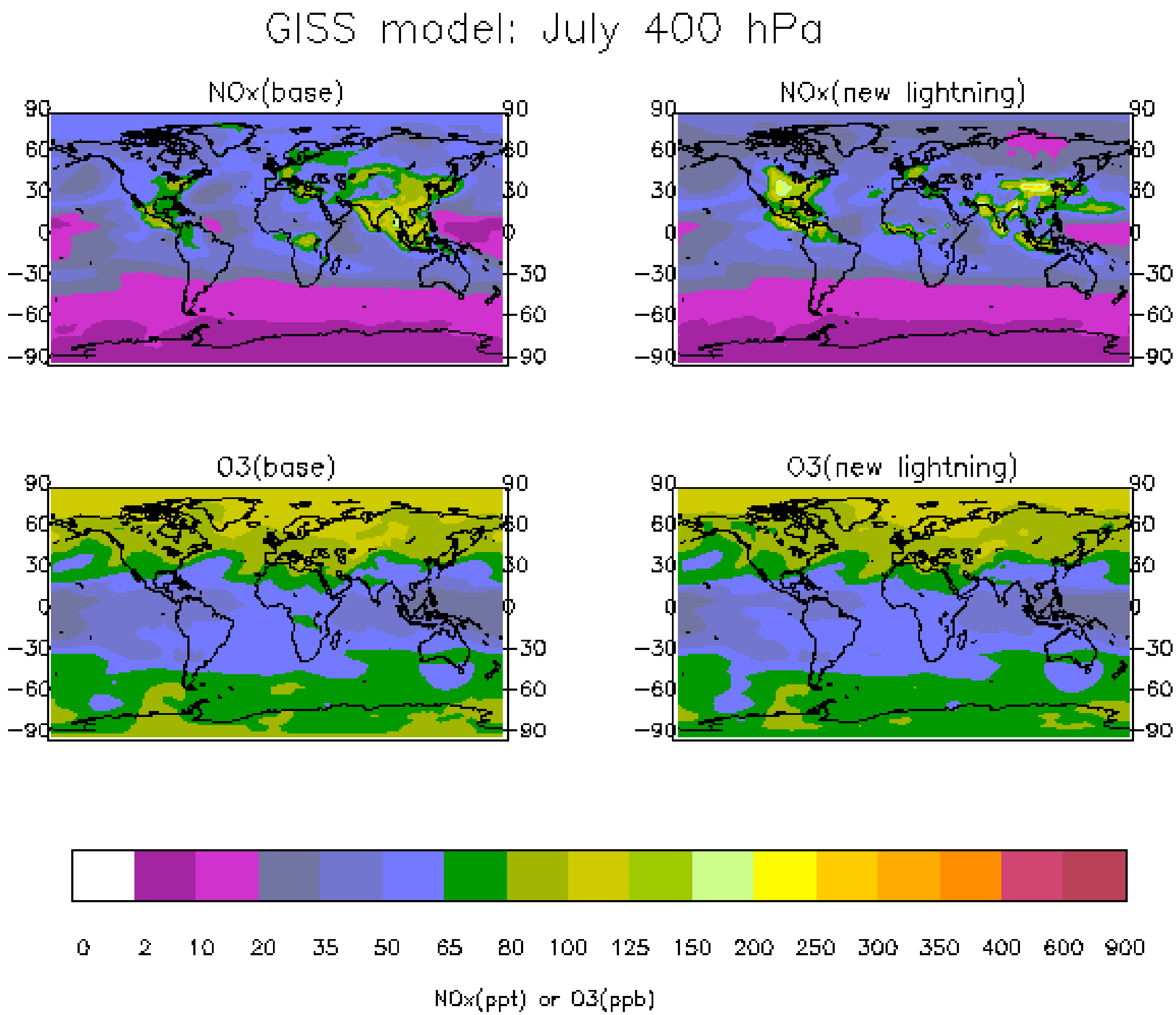


DAO model: July

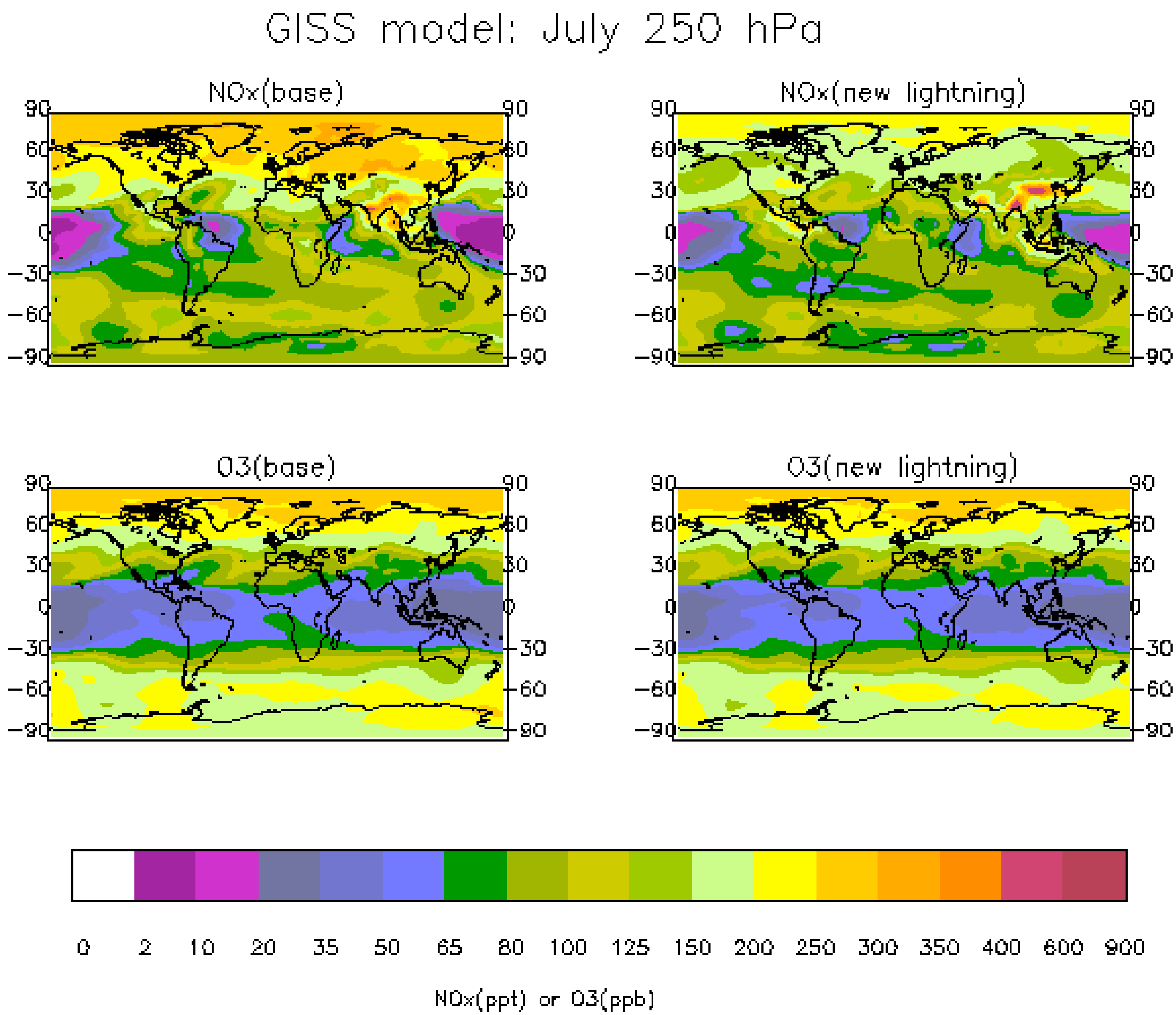



DAO model: July
HNO3(base) 400 hPa
HNO3(new) 400 hPa
HNO3(base) 250 hPa
HNO3(new) 250 hPa
90
60
30
0
−30
−60
−90
0 2 10 20 35 50 65 80 100 125 150 200 250 300 350 400 600 900 1200
HNO3 (pptv)


DAO model: July
HNO3(new−base) 400 hPa
HNO3(new−base) 250 hPa
90
60
30
0
−30
−60
−90
−300 −200 −120 −90 −70 −50 −30 −10 10 30 50 70 90 120 200 300
HNO3(pptv)

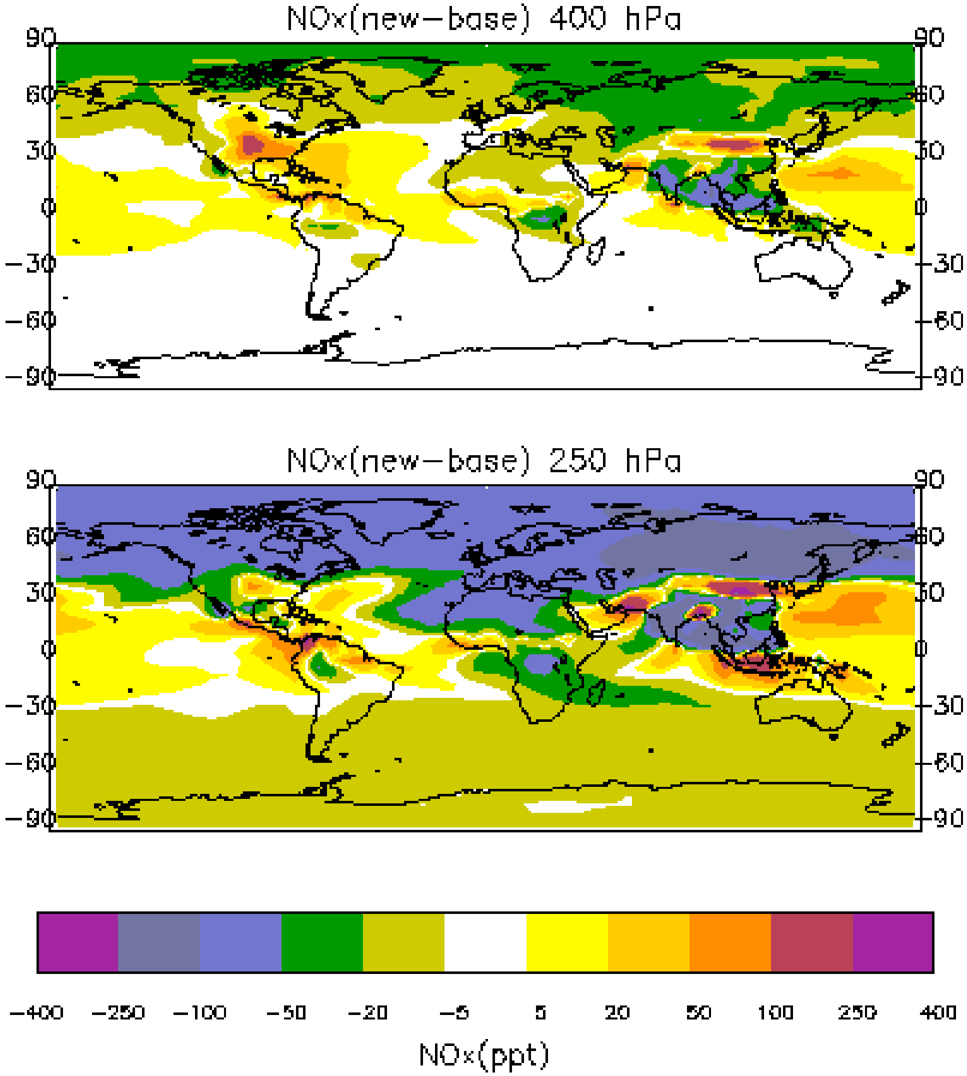


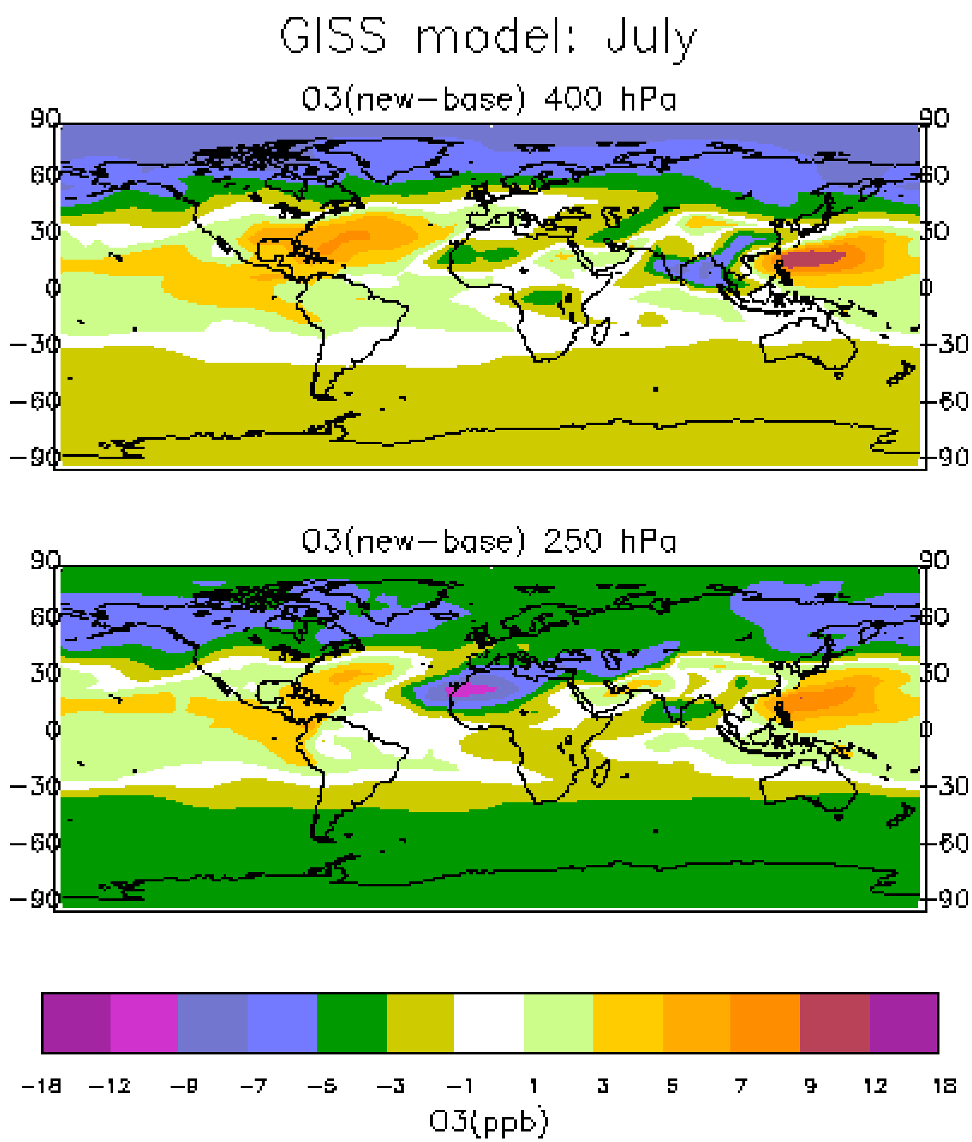
GISS model: July 400 hPa
NOx(base)
NOx(new lightning)
O3(base)
O3(new lightning)
90 60 30 0 −30 −60 −90
0 2 10 20 35 50 65 80 100 125 150 200 250 300 350 400 600 900
NOx(ppt) or O3(ppb)

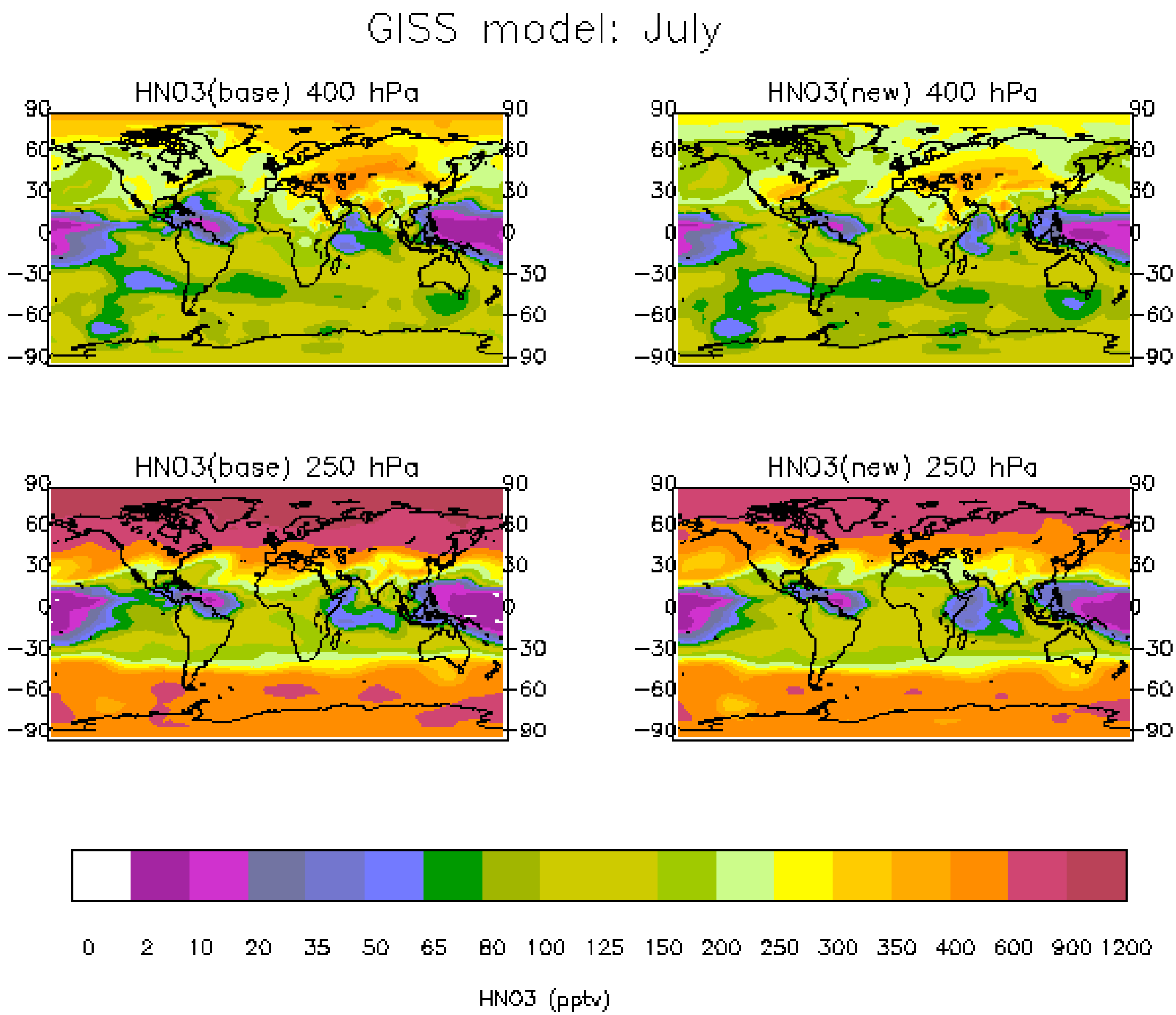


GISS model: July 250 hPa
NOx(base)
NOx(new lightning)
O3(base)
O3(new lightning)
90
60
30
0
−30
−60
−90
0 2 10 20 35 50 65 80 100 125 150 200 250 300 350 400 600 900
NOx(ppt) or O3(ppb)

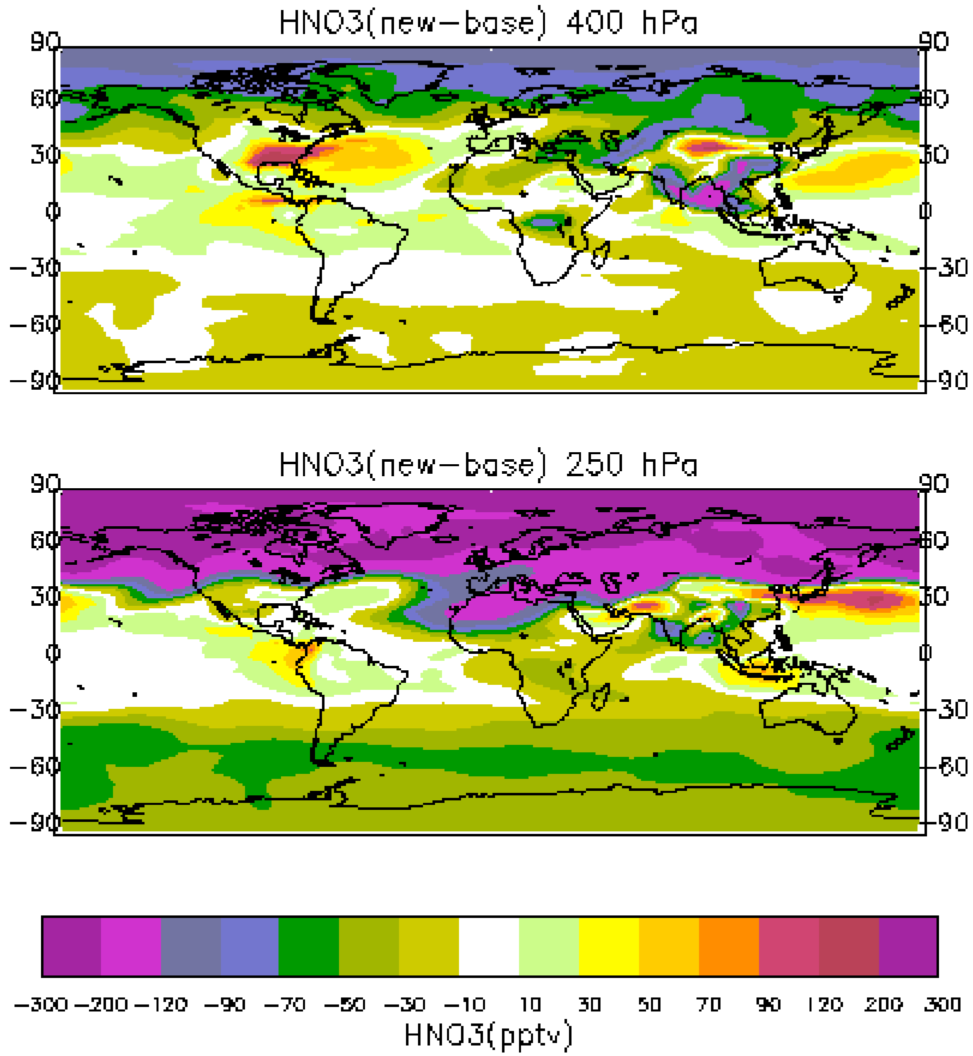
GISS model: July




GISS model: July
O3(new–base) 400 hPa
O3(new–base) 250 hPa
90
60
30
0
–30
–60
–90
–18 –12 –9 –7 –5 –3 –1 1 3 5 7 9 12 18
O3(ppb)


GISS model: July
HNO3(base) 400 hPa
HNO3(new) 400 hPa
HNO3(base) 250 hPa
HNO3(new) 250 hPa
90
60
30
0
-30
-60
-90
0 2 10 20 35 50 65 80 100 125 150 200 250 300 350 400 600 900 1200
HNO3 (pptv)

GISS model: July



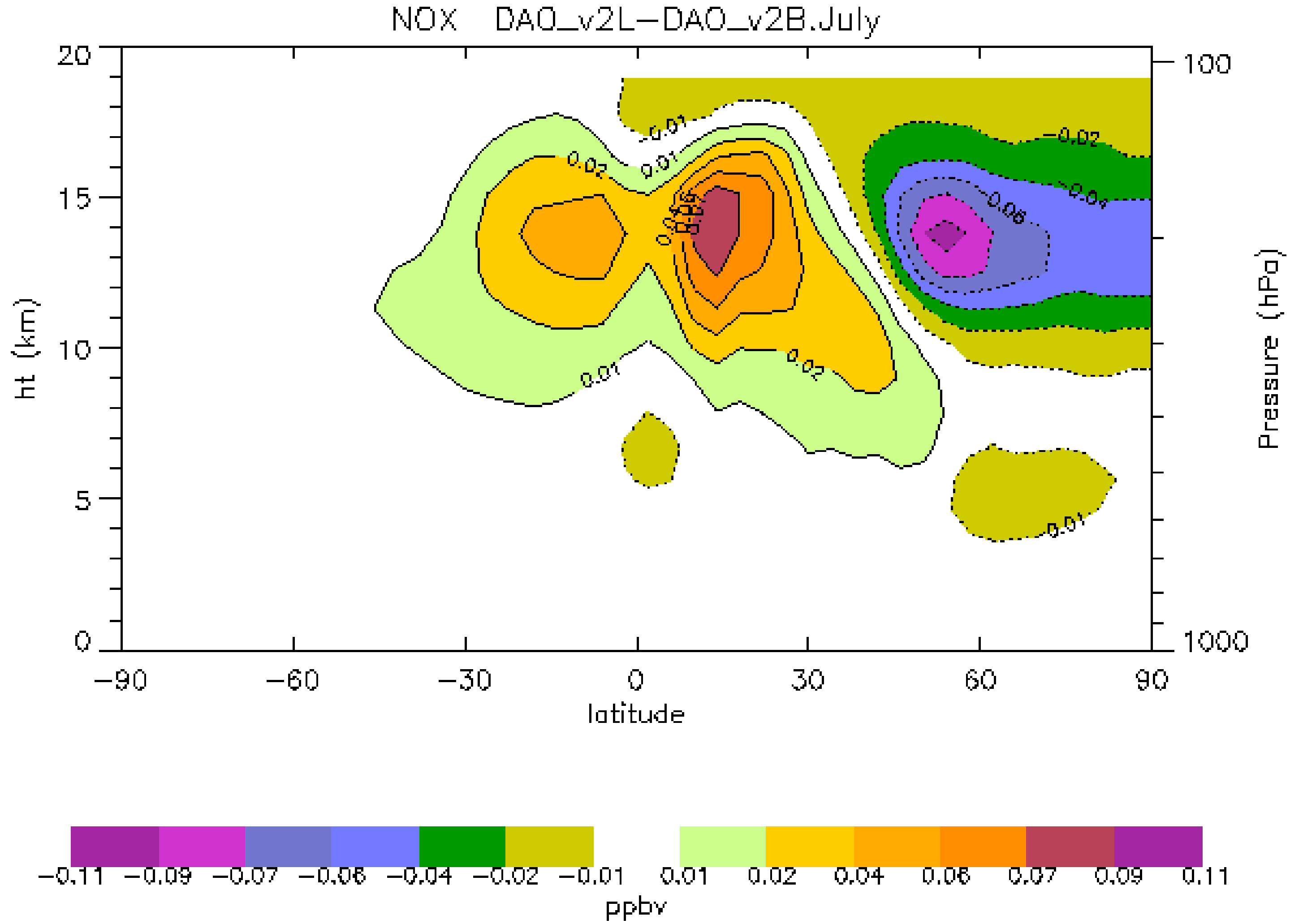
Summary

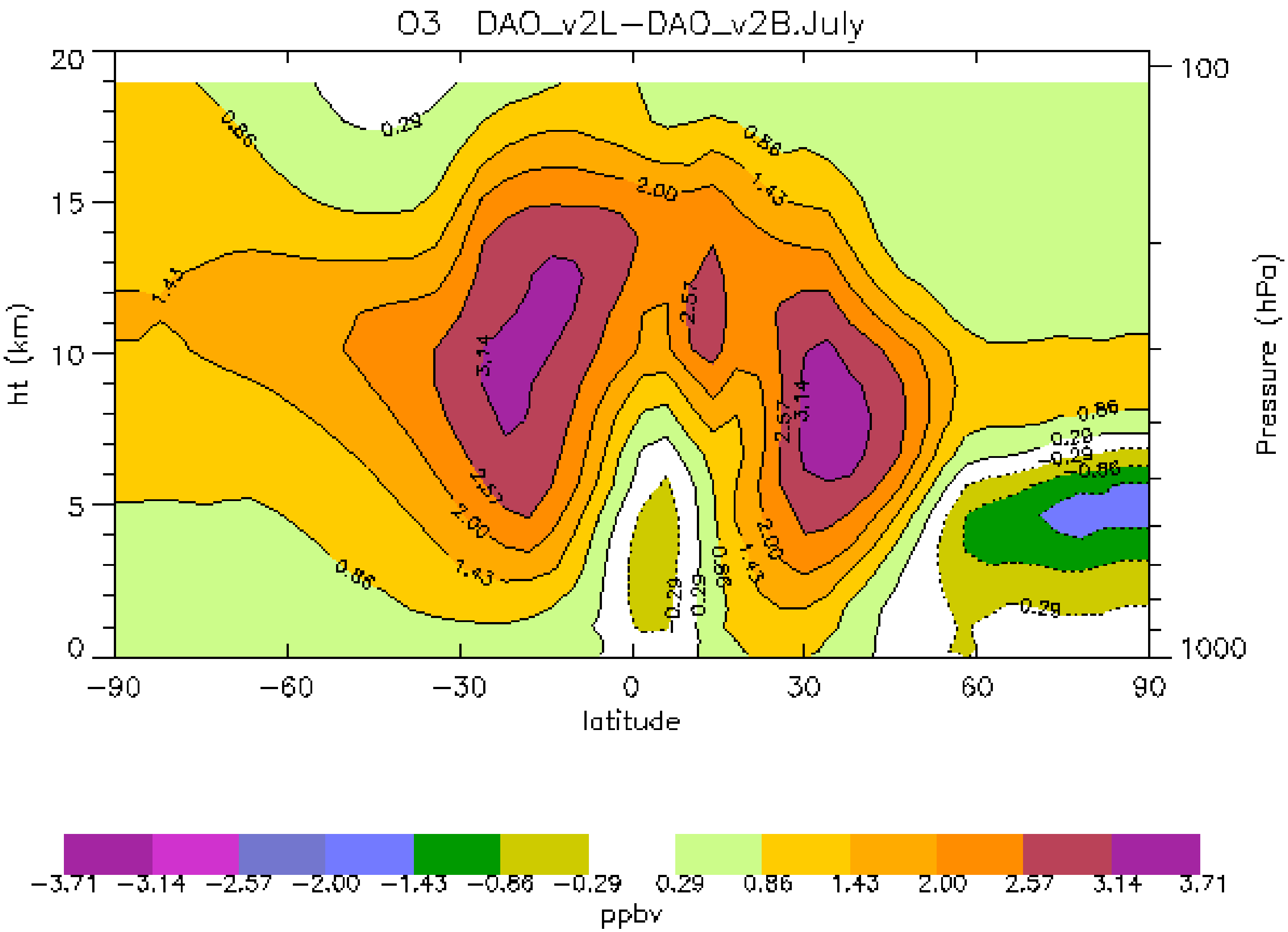
- Relationship between NLDN/LRF and normalized CLDMAS was used to derive lightning parameterizations for each of the three met. fields used by GMI.
- Flash rates at tropical marine locations were too high (normalized so that tropical marine/tropical continental flash rate ratio matches observations).
- Resulting flash rate data sets were normalized to match v1.0 LIS/OTD annual average climatological flash rate
- Test run of GMI model with DAO and GISS met. fields for one year with 5 TgN/yr from lightning.

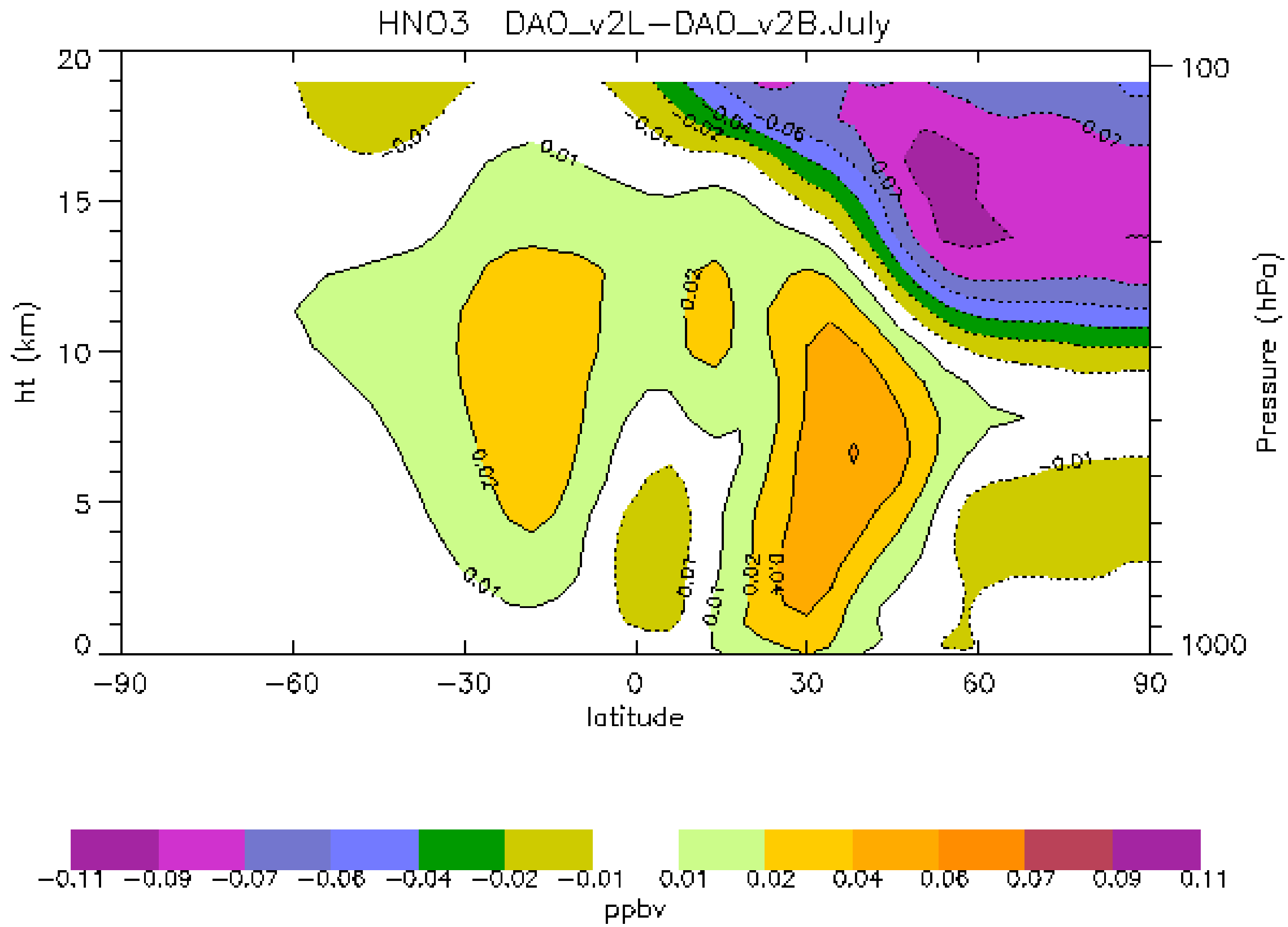
Summary

PRELIMINARY FINDINGS - JULY

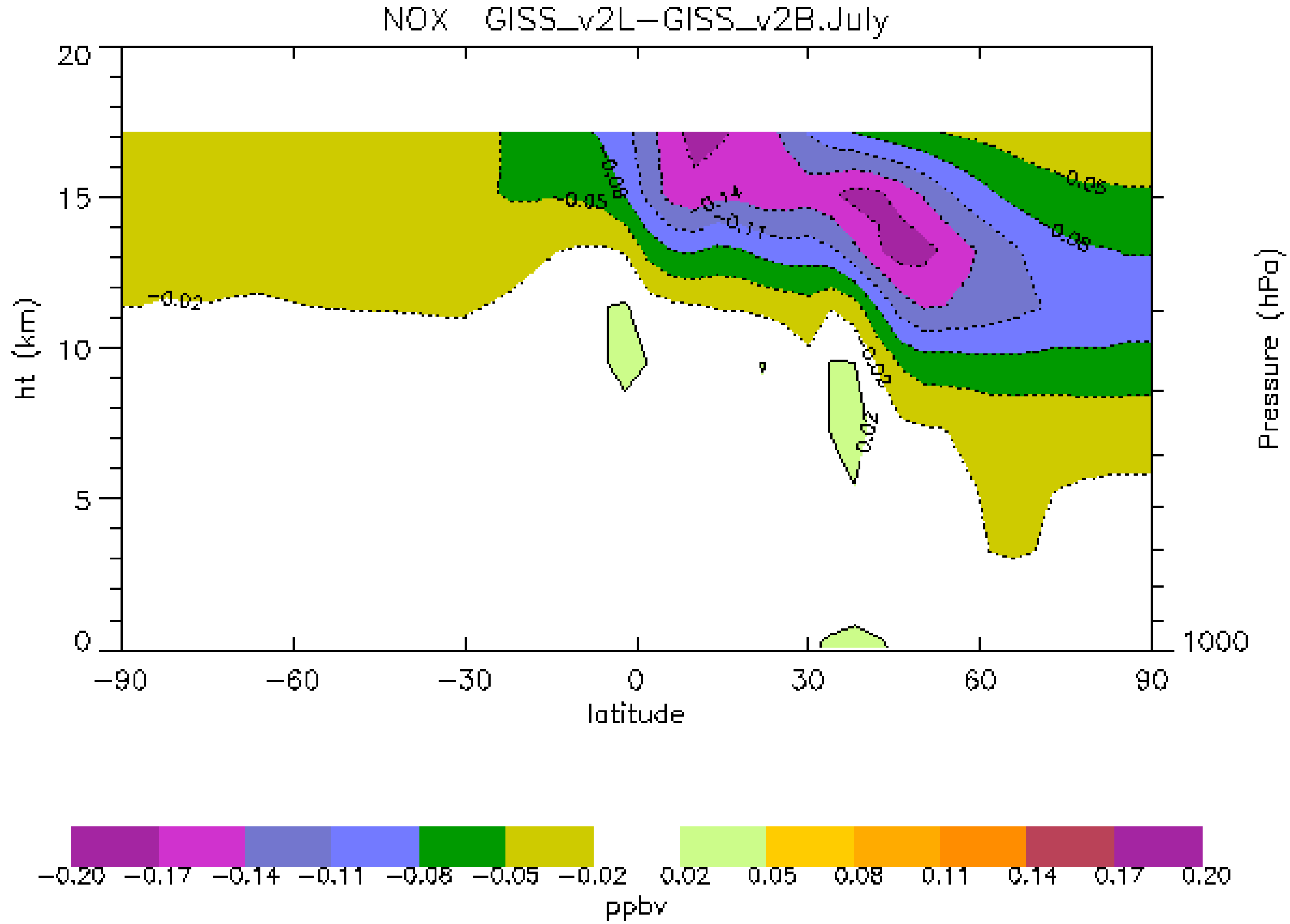
- DAO: Greatest impact of new lightning scheme is greater NOx, O3 and HNO3 in the UT over the North Atlantic
- GISS: More ozone downwind of North America and Asia

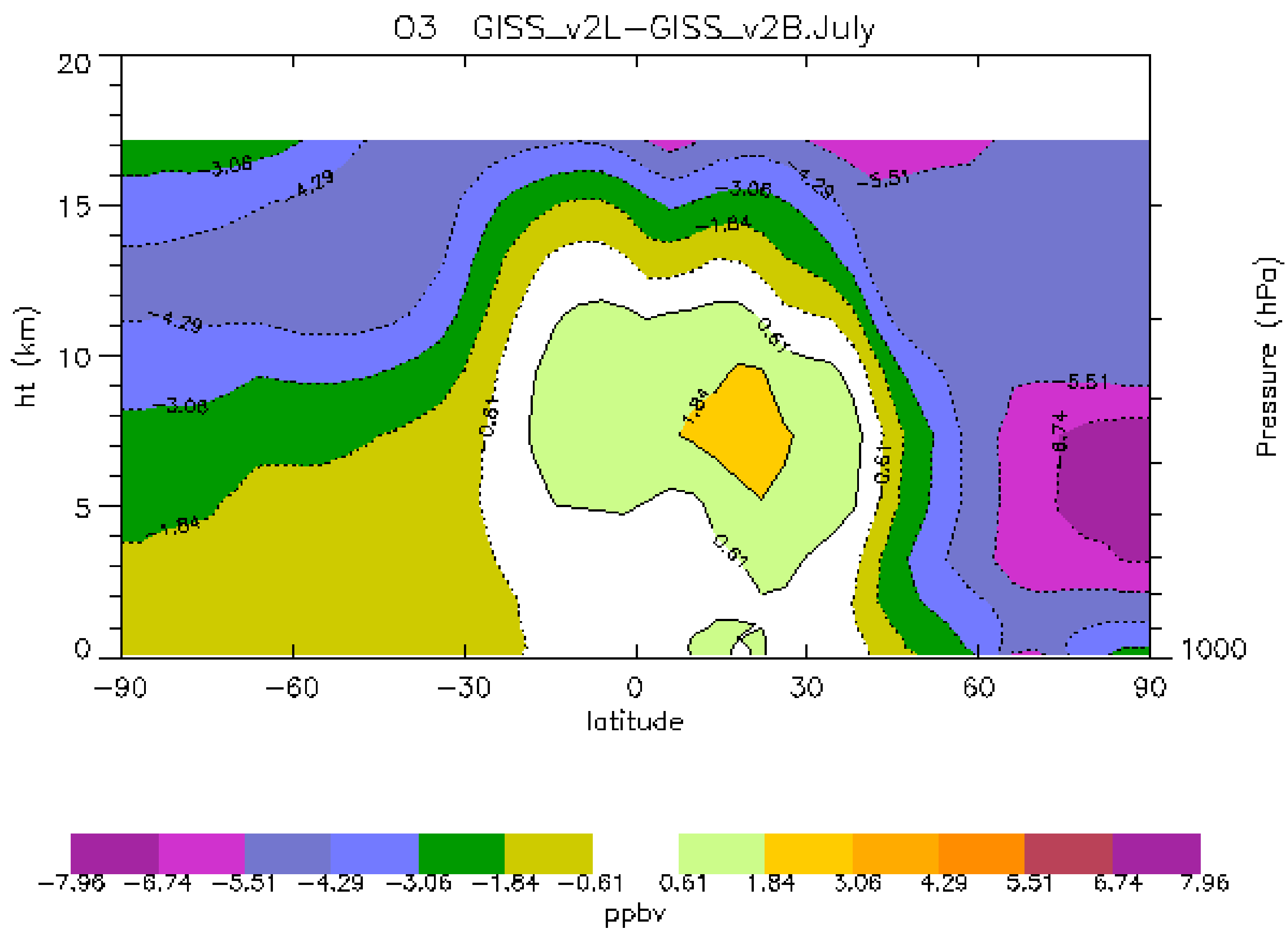

NOX DAO_v2L−DAO_v2B.July
ht (km)
Pressure (hPa)
latitude
ppbv
20
15
10
5
0
100
1000
−90
−60
−30
0
30
60
90
−0.01
−0.02
−0.04
−0.06
0.01
0.02
−0.11
−0.09
−0.07
−0.06
−0.04
−0.02
−0.01
0.01
0.02
0.04
0.06
0.07
0.09
0.11

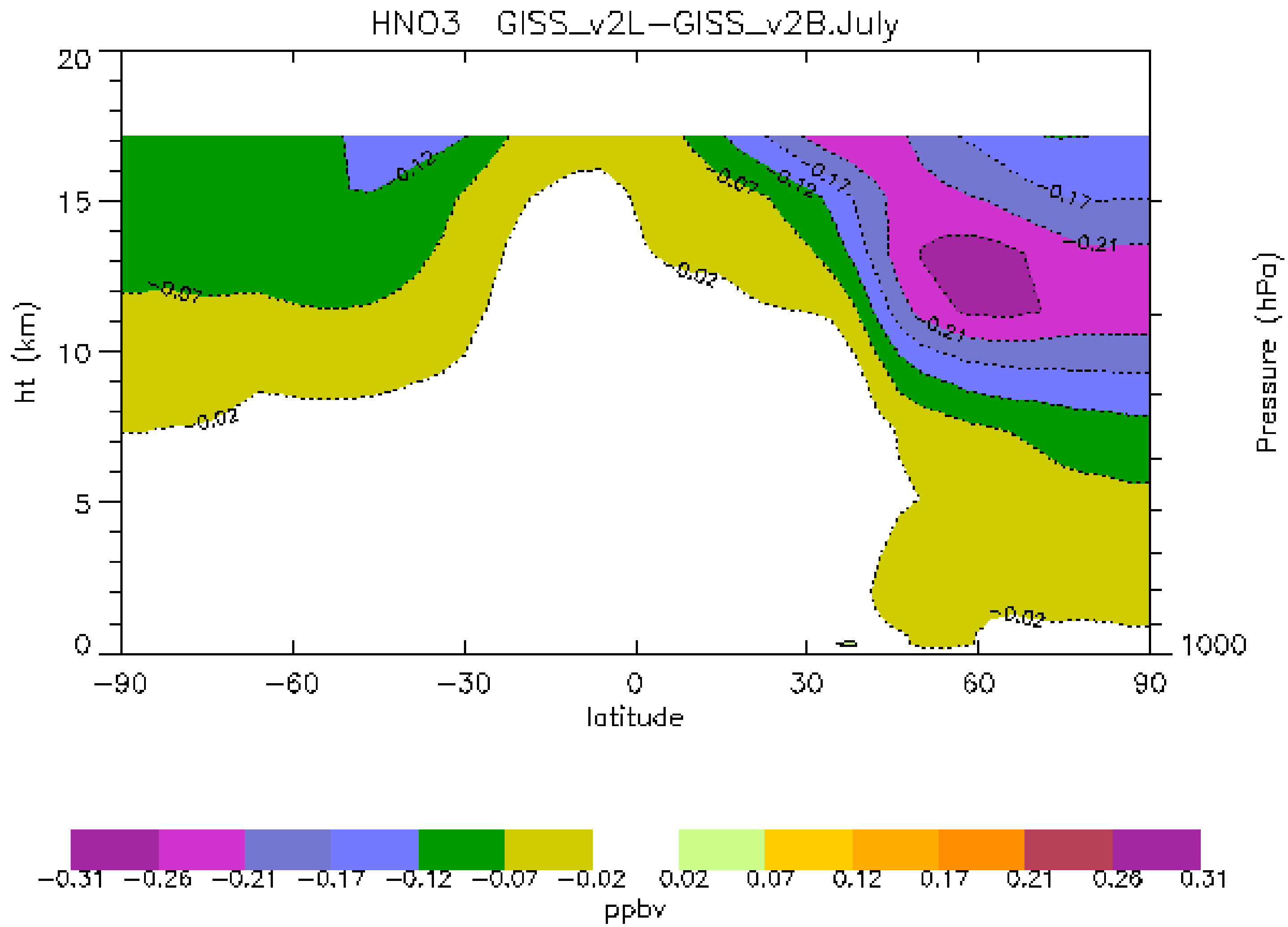

O3 DAO_v2L−DAO_v2B.July
ht (km)
Pressure (hPa)
latitude
−90
−60
−30
0
30
60
90
0
5
10
15
20
100
1000
−3.71
−3.14
−2.57
−2.00
−1.43
−0.86
−0.29
0.29
0.86
1.43
2.00
2.57
3.14
3.71
ppbv

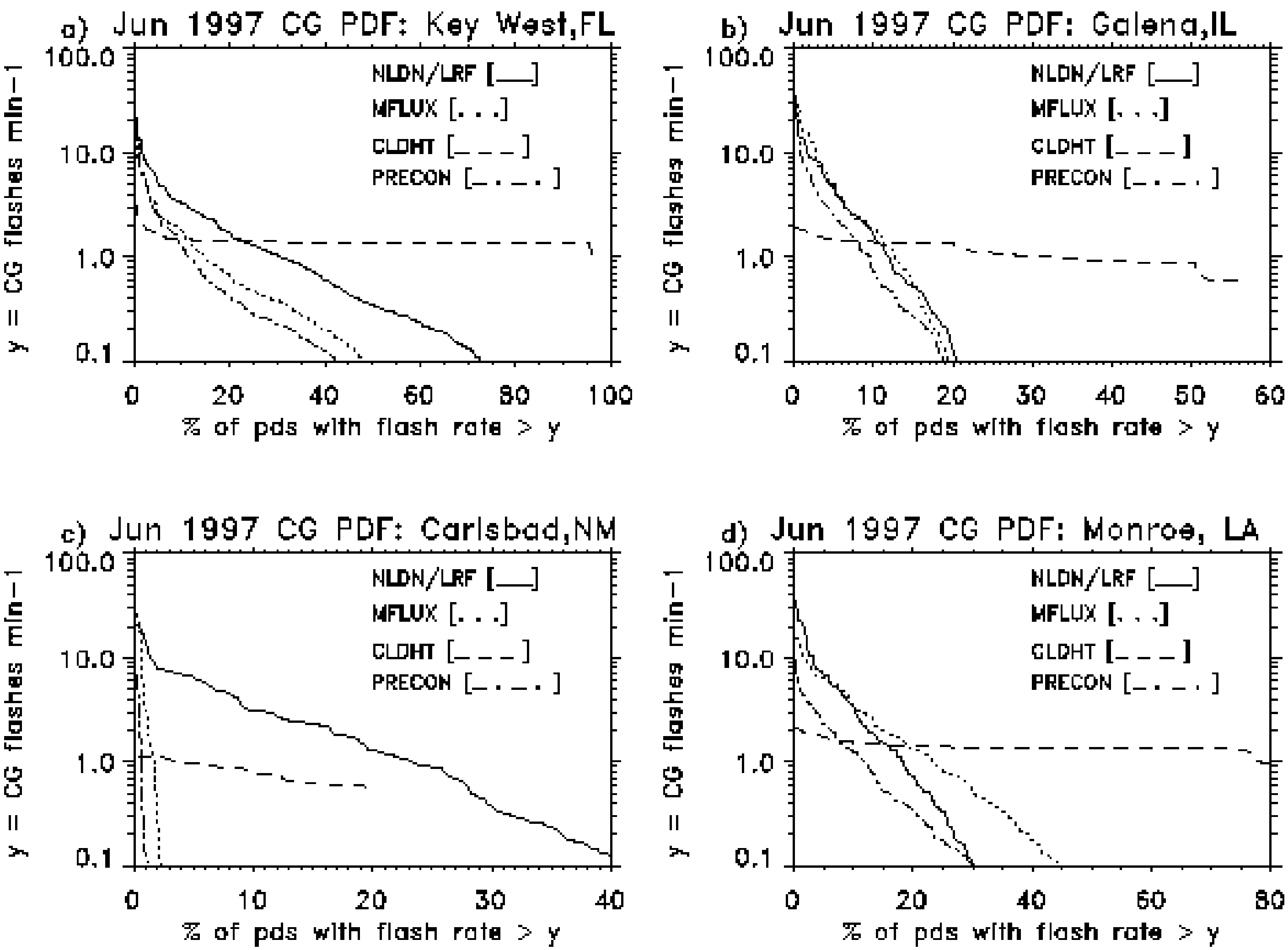


HNO3 DAO_v2L−DAO_v2B.July
ht (km)
Pressure (hPa)
latitude
ppbv
−0.11 −0.09 −0.07 −0.06 −0.04 −0.02 −0.01 0.01 0.02 0.04 0.06 0.07 0.09 0.11


NOX GISS_v2L−GISS_v2B.July
ht (km)
Pressure (hPa)
1000
latitude
−0.02
−0.05
−0.08
−0.11
−0.14
0.02
ppbv
−0.20 −0.17 −0.14 −0.11 −0.08 −0.05 −0.02 0.02 0.05 0.08 0.11 0.14 0.17 0.20

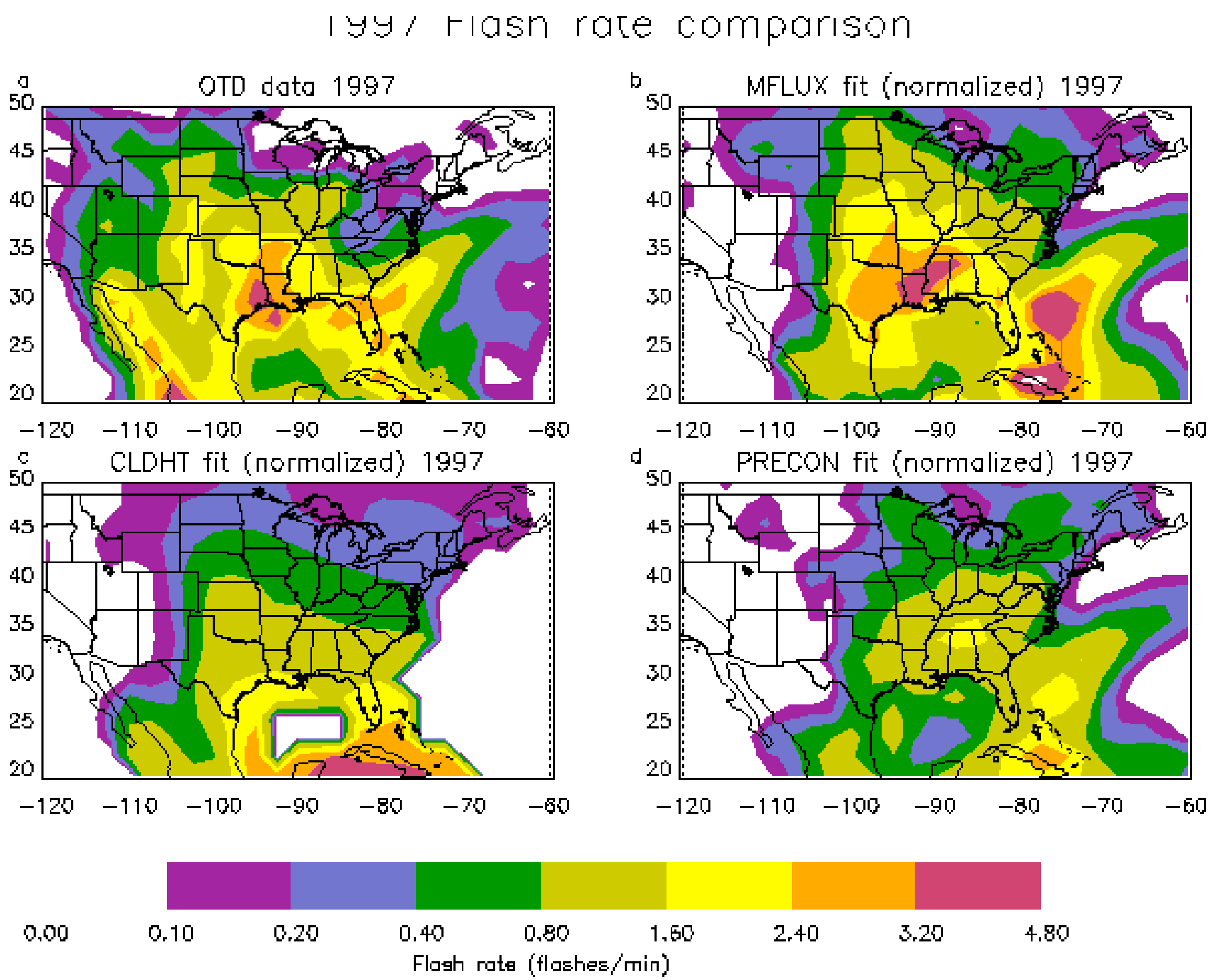

O3 GISS_v2L−GISS_v2B.July
ht (km)
Pressure (hPa)
1000
latitude
−90
−60
−30
0
30
60
90
0
5
10
15
20
−7.96
−6.74
−5.51
−4.29
−3.06
−1.84
−0.61
0.61
1.84
3.06
4.29
5.51
6.74
7.96
ppbv


HNO3 GISS_v2L−GISS_v2B.July
ht (km)
Pressure (hPa)
latitude
ppbv
−0.31 −0.26 −0.21 −0.17 −0.12 −0.07 −0.02 0.02 0.07 0.12 0.17 0.21 0.26 0.31



a) Jun 1997 CG PDF: Key West,FL
b) Jun 1997 CG PDF: Galena,IL
c) Jun 1997 CG PDF: Carlsbad,NM
d) Jun 1997 CG PDF: Monroe, LA
NLDN/LRF [___]
MFLUX [. . .]
CLDHT [_ _ _]
PRECON [_ . _ .]
y = CG flashes min−1
% of pds with flash rate > y

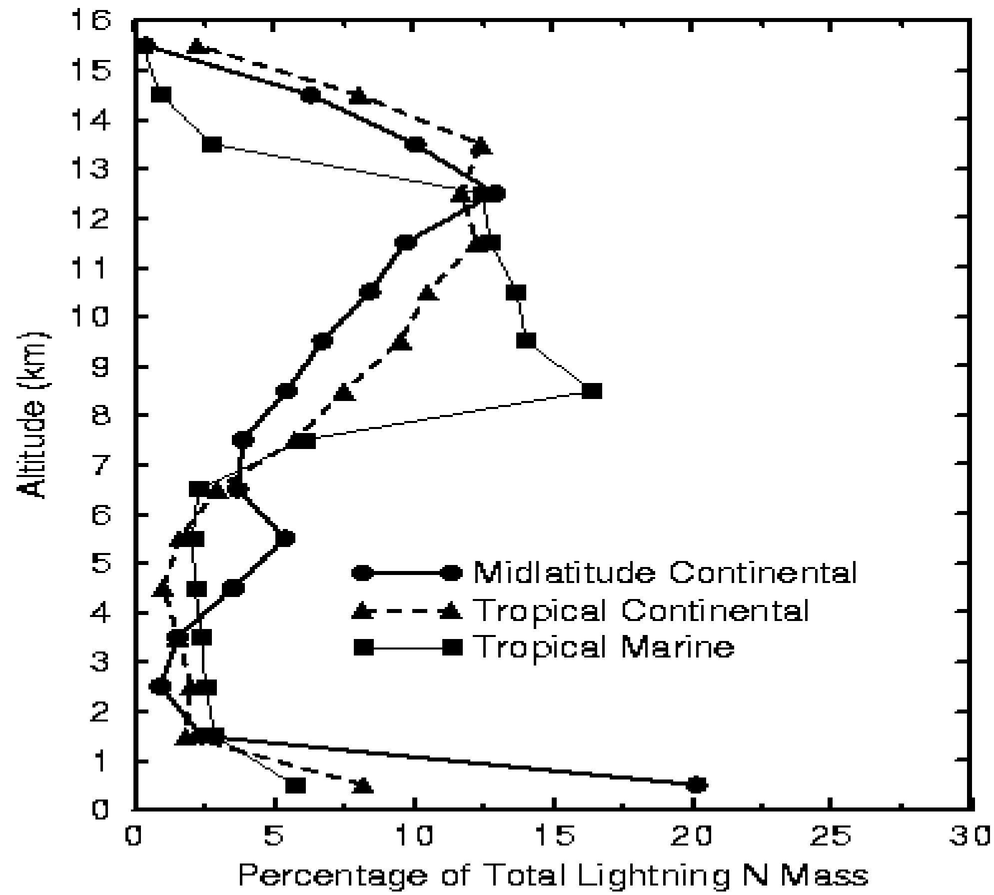
Figure 12



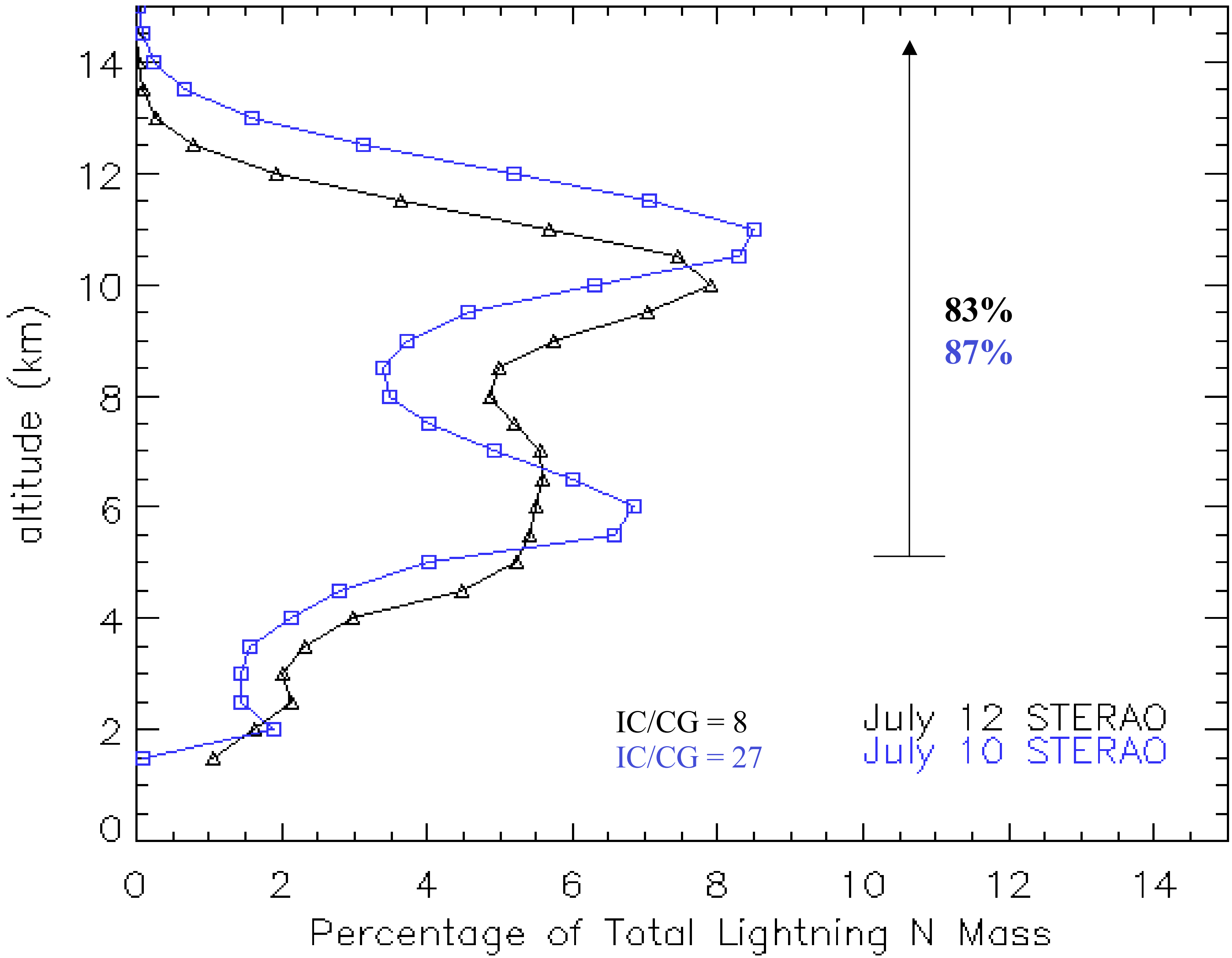
1997 Flash rate comparison
a
OTD data 1997
b
MFLUX fit (normalized) 1997
c
CLDHT fit (normalized) 1997
d
PRECON fit (normalized) 1997
50
45
40
35
30
25
20
−120 −110 −100 −90 −80 −70 −60
0.00 0.10 0.20 0.40 0.80 1.60 2.40 3.20 4.80
Flash rate (flashes/min)

Figure 11

Lightning NOx Profiles for Use in Regional and Global Chemical Transport Models



Pickering et al. (1998)



altitude (km)
Percentage of Total Lightning N Mass
0
2
4
6
8
10
12
14
83%
87%
IC/CG = 8
IC/CG = 27
July 12 STERAO
July 10 STERAO